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Sleep Impacts of Nighttime Training Noise From Large Weapons on Residents Living Near a Military Installation

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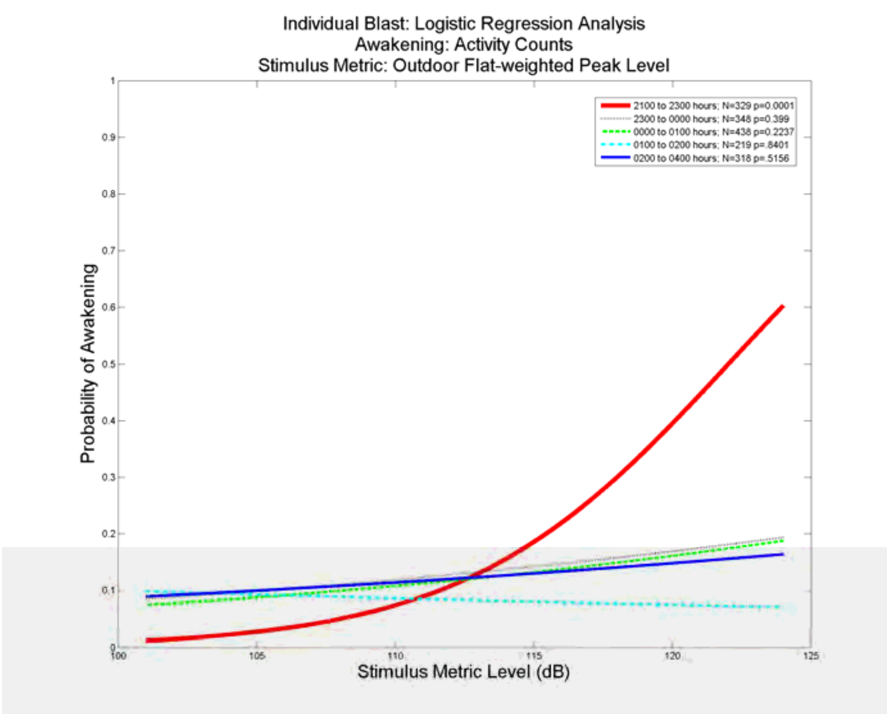
August 2006



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Final report

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Abstract: Training during the hours of darkness is a necessity for the Army and other branches of the Department of Defense (DoD). Nighttime training is needed to ensure military forces are ready for combat, but installations also endeavor to minimize community noise disturbance and resulting negative public reaction. As a result, most installations restrict nighttime training or enforce training curfews to reduce the negative impact of the nighttime training noise on local residents. There is, however, little research-based guidance on the types of restrictions and curfews needed to effectively reduce the negative impact. Consequently, current training restrictions may sacrifice more training capability than necessary.

During the fall of 2004 a field study was conducted adjacent to a military installation to determine if there are preferred times to conduct nighttime training. The results of this research project clearly and strongly indicate that community disturbance is more effectively reduced by conducting training between 0000 and 0200 hours, and avoiding noisy training during the evening hours before midnight. These findings suggest that nighttime training should be postponed until after midnight in order to effectively reduce the negative impact of nighttime training on local residents and to preserve nighttime training capabilities throughout DoD.

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Preface

This report is a deliverable product resulting from research conducted under Department of the Army project A896, "Base Facilities Environmental Quality," Work Unit 33143, "Training and Testing Range Noise Control," funded by the U.S. Army Corps of Engineers. This report was reviewed and approved by the Army's designated Technical Monitor for Training and Testing Range Noise Control, Dr. William Russell, USA CHPPM (United States Army Center for Health Promotion and Preventive Medicine) Operational Noise Program, and by a reviewer designated by the Garrison Commander of the installation at which the research was conducted.

This report was prepared by Edward T. Nykaza, Larry L. Pater, and Robert H. Melton, Ecological Processes Branch (CN-N), Installations Division (CN), Construction Engineering Research Laboratory (CERL), U.S. Army Engineer Research and Development Center (ERDC), under the general supervision of Alan B. Anderson, Chief CN-N; Dr. John T. Bandy, Chief CN; and Dr. Ilker Adiguzel, Director, CERL.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Acknowledgements

The authors of this report thank the acoustics teams at ERDC-CERL and USACHPPM for their support and guidance throughout this project. Thanks is extended to the command and staff of the installation at which the study was conducted for their cooperation and support.

The authors would like to add a special thanks to Bonnie Storey for all the time and effort she put into this project.

1 Introduction

This report documents a field study conducted as part of an investigation into the effects of noise from heavy military weaponry on the sleep patterns of residents living near a military installation. This field study was the second phase of the investigation; the first phase was a laboratory (pilot) study reported in Luz et al.[1]

Objective

The primary objective of this study was to determine if there are preferred time periods at night to conduct training; i.e., are there time periods at night where people are less likely to awaken from training noises? Previous work by Griefahn[2] and Luz et al.[3] suggests a time window may exist in the middle of the night when residents are in a deeper sleep and less likely to be awakened by blast noise. If such a time period exists, then range operators could systematically schedule nighttime training for the dual purpose of reducing the negative impact of nighttime training on local residents and preserving nighttime training capability.

A secondary objective of this study was to conduct the study *in situ*; i.e., in subjects' natural sleeping environments (their own beds) using a real stimulus (live nighttime training noise). This objective was important because there are fundamental problems with conducting sleep research in a laboratory setting (Fidell et al.).[4] Similar problems were reported in the pilot study:

1. It is difficult to perfectly reproduce the stimulus, which is especially true for the low-frequency, high-energy, and impulsive characteristics of the blast noise being tested.
2. People may be extra sensitive to noise when they are not sleeping in their normal environment; and as a result, it is arguably not appropriate to ex-

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[1] G. Luz, E. Nykaza, C. Stewart, L. Pater, *The Role of Sleep Disturbance in Predicting Community Response to the Noise of Heavy Weapons*, ERCD/CERL TR-04-26, November 2004.

[2] B. Griefahn, "Effects of military noise during sleep, Relations to sex and time of night," in B. Berglund et al., (eds) *Noise as a Public Health Problem: New Advances in Noise Research*, Swedish Council for Building Research, Stockholm, Sweden, 1990.

[3] Luz et al. 2004.

[4] Fidell, S., K. Pearsons, R. Howe, B.G. Tabachnick, L. Silvati, and D.S. Barber, "Noise-induced sleep disturbance in residential settings," BBN Report 7932, AI/OE-TR-1994-0131, February 1994.

trapolate laboratory findings into the field. Guidelines derived from laboratory studies may be overly conservative and so may needlessly restrict nighttime training operations.

Approach

Chapter 3, "Methodology" contains a detailed discussion of the approach used in this research.

Mode of Technology Transfer

The results of this field study will provide the basis for new recommendations to installations as deemed appropriate by experts at the U.S. Army Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL) and at the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM).

This report will be made accessible through the World Wide Web (WWW) at URL: http://www.cecer.army.mil

2 Literature Review

Sonic Boom Study

In 1972 Collins and Iampierto[5] conducted a laboratory study to investigate the relationship between awakening from sonic booms and age. The linear peak level of the sonic boom inside the laboratory bedroom was 110 dB. The study consisted of 24 male subjects, who were evenly distributed among the following age groups: 21 to 26 years, 40 to 45 years, and 60 to 72 years. The study found that the frequency of awakenings from all causes increased with age, but awakenings attributed to sonic boom did not increase with age. There were very few awakenings due to sonic booms across the entire group. Although the simulated booms at a peak level of 110 dB had no effect on the overall patterns of sleep, they did produce measurable changes in heart rate and basal skin resistance. These changes increased with age.

German Blast Noise Study

Barbara Griefahn conducted a laboratory study that examined the effects of blast noise on sleep. Twenty healthy subjects with normal hearing (10 female, 10 male; 20 to 30 years old) slept in the laboratory from 2300 to 0700 during 13 consecutive nights. No stimulus was presented during the first three nights, which allowed subjects to adapt to the sleep environment. On the 4th night 23 randomly distributed blasts were presented to the 12 subjects in the “evening” group (2300 to 0200) and the 8 subjects in the “morning” group (0400 to 0700). The stimulus, a 120-mm tank cannon at 1.5 km behind the firing line, was reproduced from a high-quality video recorder. The set of 23 blasts was repeated on the 7th, 10th, and 13th night for a total of 1,840 trials across the total subject pool. Approximately a quarter of the trials resulted in awakenings (as defined by EEG readings) and about 80 percent resulted in movement. This information comes from Figure 1 in Griefahn’s paper, “Effects of military noise during sleep: relations to sex and time of night,” *Proceedings of the 5th International Congress on Noise as a Public Health Problem*, 1988, pp 39-48. The figure shows approximately 480 ten-second epochs as “awake” during the ten-second epoch of the stimulus presentation. In the second

[5] W.E. Collins and P.F. Iampietro, “Simulated Sonic Booms and Sleep: Effects of Repeated Booms of 1.0 PSF,” FAA-AM-72-35, FAA Civil Aeromedical Institute, Oklahoma City, 1972.

panel, movements during the ten-second epoch after the stimulus presentation appear to number about 80. Presumably, the scale in the second panel is percent. The study found that there is a greater likelihood of awakening between 0400 and 0700 than between 2300 and 0200.

Pilot Study

In 2002, a pilot study[6] was conducted that preceded the present study. It was conducted in the Hostile Environment Simulator (HES) chamber operated by the Human Research and Engineering Directorate (HRED) of the Army Research Laboratory (ARL) at Aberdeen Proving Ground (APG), MD. Subjects wore commercially available actimeters and slept in the chamber for a total of 4 nights between the hours of 2200 to 0600.

Methods

Fifteen subjects were tested and included in the analysis. No acoustic stimulus was presented on the first two nights to allow the subjects to become accustomed to the chamber. On the 3rd and 4th nights, subjects were exposed to electronically reproduced recordings of blast noise from a 120-mm tank cannon. Two blasts were presented at the rate of one pair per hour, beginning at 2300 and ending by 0500. There were 6 pairs of blasts each night. One of each pair was at a peak level of 110 dB and the other at a peak level of 120 dB. The time of each event was chosen randomly so that in any given hour, the lesser blast had the same probability of coming first as did the greater blast.

Responses to the blast noise were measured by means of actimeters (described in detail in Chapter 3, "Methodology") in two ways. The first was a button push by a subject within 15 seconds of the occurrence of a blast. The second was comparison of activity counts measured by the actimeter during the 30-second period before a blast and the 15-second period after a blast.

Results

The pilot study found that blast noise presented at a peak level of 120 dB was approximately 1.5 times more likely to wake someone than blast noise at 110 dB, regardless of the way the response to the blast noise was measured (i.e., button press or movement indicated by activity counts). This re-

[6] Luz et al. 2004.

sult was significant at the $p < 0.10$ level. It was also found that time had a slight effect on awakening. Subjects were more likely to respond to the stimulus between the times of 2300 to 2400 compared to 2400 to 0400.

It was observed that the activity count was a more sensitive measure of awakening than button presses. In other words, there were times when people moved in response to the blast but did not press the button to indicate they woke up from the blast.

The pilot study concluded that during the shoulder hours (2300 to 0000 and 0400 to 0500) stimulus decibel level differences were an import variable in awakening. Shoulder hours refer to the beginning and end of the night (i.e., the period right before sleep onset and the period prior to awakening in the morning). The differences between the levels of the stimulus has a smaller effect between the hours of 0000 to 0400 hours, which was hypothesized to be due to subjects being in a deeper sleep during those hours. It was also observed that 50 percent of the 120 dB blasts did not cause an awakening between 0000 and 0400.

3 Methodology

Subject Selection

Address lists of residents living near the military installation were compiled from www.whitepages.com. Subjects were recruited by mail (Appendix A). The initial mailing included a letter from the Garrison Commander of the military installation describing the study, a postage paid return envelope, and a short questionnaire to indicate interest in the study.

Approximately 600 letters were sent out and 148 residents responded. Potential subjects were screened according to the following criteria:

- Must not be deaf (although no audiograms were given)
- Must not have a sleep disorder
- Must not be pregnant
- Must be between the ages of 18-75
- Must sleep at home for the duration of the study
- Must sleep between the hours of 2200-0800
- Must be a resident of the area for at least 1 year
- Must be willing to have equipment in bedroom and outside home
- Must be willing to fill out daily questionnaire and wear actimeter every night.

Due to the limited number of responses and relatively small blast noise impact area, subjects that met the above criteria were chosen on the basis of proximity to the nearest firing point. This precluded achievement of a strictly random sample. However, the sample was representative of the census tract from which it was drawn, as reported in Chapter 4, “Results.”

Out of the 148 responding residents, 50 were contacted via telephone to set up face-to-face interviews and 48 interviews were scheduled. During the face-to-face interviews, the study was explained in detail and the potential subjects were given an opportunity to ask questions and address concerns. Noise monitors and actimeters were brought to the interview to give potential subjects an opportunity to see the equipment. The face-to-face interviews also gave the research team a chance to meet the subjects,

locate their homes, and arrange the deployment of equipment at each location.

Of the 48 interviews, 45 subjects agreed to participate in the subject. Given the high agreement percentage, an additional 12 subjects were taken out of the subject pool because of limited equipment availability, making the final subject pool consist of 33 subjects. Subjects that lived furthest from the firing points were removed from the study. Appendix B contains the letter sent to the subjects that schedules the times for equipment installation, check, and removal.

At the time of the equipment installation, instructions and demonstrations were given to each subject on how to use the actimeter. A paper copy of the instructions was given to each subject, including a 24-hour toll free number they could call if they had any problems or questions. The instructions are included in Appendix C. Subjects also were given a questionnaire and asked to complete it each morning. The questionnaire contained questions regarding the previous day and their night of sleep. The morning questionnaire is included in Appendix D.

Each subject was paid $15 per night that they participated in the study. The average length each subject participated was 21 nights.

Sound Measurement

Ambient and blast event sound levels were documented indoors and outdoors at each data collection site; each noise monitor recorded 1-sec Sound Exposure Level (SEL) or Equivalent Continuous Noise Level (Leq)[7], 1/3 octave SEL, and peak levels between 2000 and 0800 hours. Each measurement was A-, C-, and Flat-weighted. The outdoor monitors were also set up to record noise events. A noise event was defined as a noise level that exceeded a C-weighted peak threshold level of 100 dB. For each noise event, noise stimulus metric levels were recorded during a time period from 1 sec before the event to 5 sec after the event, and a recording of the event was made for later reference and source identification. The wave file was recorded only on the outdoor microphone to protect the subject's privacy.

[7] SEL and Leq are equivalent at a 1-sec duration.

All outdoor noise measurements were made with Norsonic 121 noise monitors. The outdoor microphones were located at least 3 m from the subjects' windows and any other reflective surfaces. There were a few instances where neighbors with adjacent homes participated in the study. In these situations one outdoor microphone was used as the outdoor measurements for both subjects.

Indoor noise measurements were also made in each subject's bedroom with either the 2nd channel of the Norsonic 121 noise monitors or with Larson Davis 870 noise monitors. The frequency range of the Norsonic units was 6.3 hertz (Hz) to 5 kHz, and that of the Larson Davis 870 unit was 5 Hz to 16 kHz. Each microphone was located 2 m from each wall (if possible). These bandwidths are adequate; SEL spectrum for a typical blast event is shown in Figure 1.

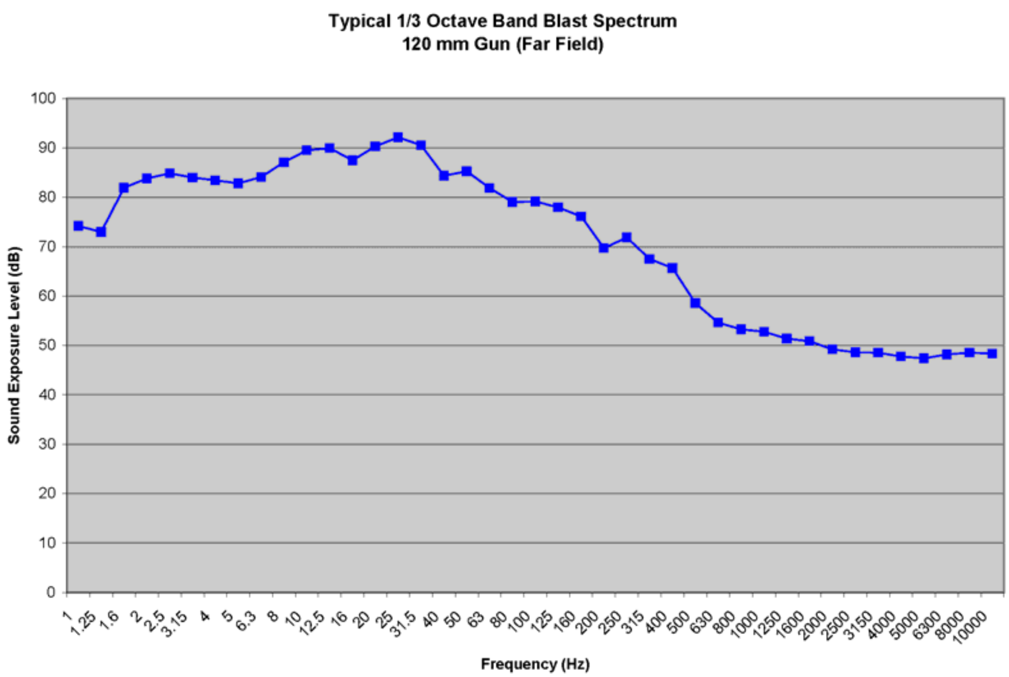


Figure 1. Typical 1/3 octave band blast spectrum from a 120 mm gun measured in the far field.

Sleep Monitors

Each subject wore a commercially available actimeter, the Mini Mitter Actiwatch® each night of the study. This actimeter, shown in Figure 2, was an integrating actimeter; the sensor integrates the degree and speed of motion and produces an electrical current that varies in magnitude. The in-

crease in degree of speed and motion produces an increase in voltage, which is stored as an activity count. The maximum sampling rate of these actimeters was 32 Hz. The accuracy and reliability of the actimeter data has been documented in Oakley[8], Kushida et al.[9], and the pilot study (Luz et al[10]). The actimeter was also equipped with a marker switch that was inset on the device's front panel. The marker switch provided tactile feedback informing the subject of a successful marking of the time and date (referred to as a button press throughout this report).

Figure 2. The actimeter.

Data Acquisition Schedule

The noise events that served as stimuli for this research were from large weapons that were fired during a pre-deployment training period of approximately 6 weeks spanning 21 September to 31 October, 2004. As many subjects as possible participated throughout this time period and within the limits of personal schedules and available equipment.

Throughout the field study, subjects wore the actimeters each night they participated in the study. Subjects were instructed to press an inset button on the actimeter when they first got into bed for the night, when they got out of bed in the morning, and when they woke up during the night for any

[8] N. Oakley, *Validation with Polysomnography of the Sleepwatch Sleep/Wake Scoring Algorithm used by the Actiwatch Activity Monitoring System,* Cambridge Neurotechnology Ltd, PO Box 809, Cambridge CB2 6TQ, UK.

[9] C. Kushida, A. Chang, C. Gadkary, C. Guilleminault, O. Carillo, W. Dement, "Comparison of actigraphic, polysomnographic, and subjective assessment of sleep parameters in sleep-disordered patients," *Sleep Medicine* 2 (2001) 389-396.

[10] Luz et al. 2004.

reason. Each morning, subjects answered a few questions regarding the previous day and their night of sleep.

Time Drift Correction

The internal clocks of both the sleep and noise monitors used during the study had a time drift that was corrected during data analysis to aid in correlation of noise event stimuli and sleep responses.

Noise Monitors

The noise monitors were manually calibrated to the "correct" time via an atomic watch prior to their use. The time drift was then calculated by comparing the "correct" time on an atomic watch to the time on the monitor at the end of their use. The time drift correction was done under the assumption that the time drift was linear. This assumption was reasonable given the relatively small amount of time drift (the monitors drifted no more than 1 minute over the course of 11 days), and that the observed time drift in the laboratory was linear.

Sleep Monitors

The internal clocks of the actimeters were also calibrated to the "correct" time via atomic watch prior to their use; however, these actimeters did not allow for direct comparison of the "correct" time to the internal clock time at the end of a usage period. A series of post-study experiments were conducted to determine the amount of time drift for each actimeter. The actimeters were tested at different temperatures to determine if the time drift was dependent on the temperature. The results of the post-study experiment found that each actimeter had a unique time drift and that the time drift was not dependent on temperature. The measured time drift was used to correct all data for each actimeter.

Operational Definitions

Noise Events

A noise event was defined as an outdoor sound level that exceeded a peak C-weighted threshold level of 100 dB. A wave file was recorded for each of 3101 events. Each event was audited to determine whether it was a blast or non-blast event. Of the 3101 events recorded, 2845 events were blast events and 256 were non-blast events. The most common non-blast events

included wind, rain, and thunder. A detailed analysis of the effects of non-blast events on sleep was not conducted given the relatively small number of non-blast events.

Response Evaluation Criteria

For each blast event that a subject experienced, it was determined whether the subject was already awake (AA) when the blast occurred, if the subject woke up (WU) from the blast, or if the subject slept through (ST) the blast event. In order to determine the subject response to each blast event, an appropriate evaluation period had to be chosen. The evaluation period was defined as the length of the time window, before and after the blast event, within which the subjects' sleep state was determined. The evaluation period chosen was 60 seconds. The before-the-blast evaluation period was defined as ($-60 \leq \tau < 0$) and the after-the-blast evaluation period was defined as ($0 \leq \tau < 60$). As is clearly shown in Table 1, this length was chosen because the majority of button presses occurred 0 to 45 seconds after the blast event. This fortuitously short evaluation period largely avoided overlap of consecutive evaluation periods when blast events were temporally closely spaced. In the case that two blasts occurred within an evaluation period, the blasts were analyzed in sequence. If the person slept through the first blast, then it was assumed that the person was sleeping when the second blast occurred. If the person awoke from the first blast, then it was assumed that the subject was already awake when the second blast occurred.

Table 1. Subjects' responses to blast events.

Time Relative to the Blast Event (τ in seconds)	Percentage of Button Presses (number of button presses)/ (total number of button presses)
$-60 \leq \tau < -45$	1.44
$-45 \leq \tau < -30$	0.86
$-30 \leq \tau < -15$	1.44
$-15 \leq \tau < 0$	3.46
$0 \leq \tau < 15$	8.36
$15 \leq \tau < 30$	14.70
$30 \leq \tau < 45$	5.76
$45 \leq \tau < 60$	3.17
$60 \leq \tau < 75$	1.44

Awakenings

Sleep awakenings were defined in two ways: Awakenings based on Button Presses (BP) and awakenings calculated from Activity Counts (AC). BP occurred when subjects pressed the button on their actimeter to indicate that they had been awakened. AC were based on the amount of motion as calculated by an algorithm provided by the actimeter company. The Mini Mitter® algorithm was the same as was used in the pilot study.

The actimeter used in this study was an integrating actimeter, i.e. the degree of motion reported for each time bin was calculated by integrating the amount of motion from the start of the time bin to the end of the time bin. The Mini Mitter® algorithm[11] used to calculate whether the subject was asleep or awake for each time bin is given below:

$$AC(\beta_0) = 4\,\beta_0 + 0.2[\beta_{-4} + \beta_{-3} + \beta_{-2} + \beta_{-1} + \beta_1 + \beta_2 + \beta_3 + \beta_4] + 0.04[\beta_{-8} + \beta_{-7} + \beta_{-6} + \beta_{-5} + \beta_5 + \beta_6 + \beta_7 + \beta_8]$$

where:

$AC(\beta_0)$ = the Activity Count for time bin of interest
β_0 = the time bin of interest
β_n = the time bin relative to the time bin of interest

The minimum available time bin length of 15 seconds was used for this study. Therefore, the algorithm used to determine sleep state was based on the weighted sum of AC that occured within 2 minutes before and after a stimulus event. The sleep state is calculated according to the following criteria as suggested by the manufacturer and as used in pilot study:

$$\text{Sleep} = AC(\beta_0) \leq 40$$
$$\text{Wake} = AC(\beta_0) > 40$$

Data Analysis

The data were analyzed in two ways to look at the effect of blast noise on overall sleep quality and to determine if there are preferred time periods at night to conduct nighttime training. The analyses are referred to as Overnight Analyses and Individual Blast Analyses.

[11] Instruction Manual Software Version 3.3 and earlier, Mini Mitter Part Number 910-0007-08, www.minimitter.com, 2001.

All regression analyses were performed using SAS® version 8.02, using Windows version 5.1.2600, on a Dell™ Latitude D600 PC with an Intel® Pentium 1.80 GHz processor. Significance for the regression analyses in this report are defined at the alpha < 0.05 level.

Overnight Analyses

To analyze the effects of blast noise on overall sleep quality over the entire night, a windowed subset of data was generated from the blast dataset by restricting the data to the times between the time when a subject went to bed and the time the subject arose out of bed on a given morning. Definitions of the variables used in the overnight analyses are given in Appendix E and the analyses performed are summarized in Appendix F. Dependent variables analyzed were: mean sleep bout time, mean wake bout time, total time in bed, proportion of the night awake, count of button pushes, response to question 5 (How well did you sleep last night?), and bedtime (note: the data for the analysis of bedtime were windowed to a special “bedtime” time frame from 21:00 to 23:00). Only nights that included at least one blast were included in the analyses. Each analysis also included a baseline covariate that was calculated as the median of the mean values of the dependent variable, for all nights in which there were no blasts recorded. Other covariates used were the recorded bedtime for that night (measured as hours after 2000), subject age (yr), sex (male=0, female=1), and the number of years resident. Separate analyses were run, for each dependent variable, using each independent variable listed in Appendix E.

General linear models analyses were performed using the SAS GLM procedure. No transformations were applied, since plots of residual vs. predicted values appeared reasonably homoscedastic in all cases. Logistic regressions were performed using the SAS LOGISTIC procedure, with input in the “trials/responses” format. Correction for overdispersion was achieved by including the “SCALE = WILLIAMS” option in the model statement. Negative binomial regressions were performed using the SAS GENMOD procedure with options “DIST = NEGBIN” and “OFFSET = LNSLPDUR,” where LNSLPDUR was the natural logarithm of the variable SlpDuration described in Appendix E. Use of total time in bed as an offset variable served to correct the count of button pushes for subject-night variability of the time in bed.

Individual Blast Analyses

Individual blast logistic regression analyses were conducted to understand the functional relationship between stimulus noise metrics and awakenings. In each analysis, data points in which the subject was determined to be awake within the designated time window before the blast event were excluded from the analysis. In essence, these analyses looked at the effect of each blast event experienced by subjects when they were determined to be asleep.

In order to determine if there are preferred time periods to conduct nighttime training, the dataset for the entire study was divided into 5 time categories (2100 - 2300, 2300 - 0000, 0000 - 0100, 0100 - 0200, and 0200 - 0400). Divisions of the time categories were made with the goal of having an equal number of data points in each time period and choosing meaningful time periods.

Each analysis was run separately for each combination of the two definitions of the response metric awakenings (activity counts and button presses) with each the following set of independent variables:

Outdoor_LAPeak	Outdoor_LCPeak	Outdoor_LZPeak
Outdoor_LAE	Outdoor_LCE	Outdoor_LZE
Indoor_LAPeak	Indoor_LCPeak	Indoor_LZPeak
Indoor_LAE	Indoor_LCE	Indoor_LZE

Two dependent variables, each a binary variable (0 = asleep after blast, 1 = awake after blast), were examined: Awak60_Activity and Awak60_Button (Appendix G). The dependent variables with "Activity" in the name used criteria for wakefulness that were based on actimeter Activity Count data. Variables with "Button" in the name used wakefulness criteria that were based on Button Presses. Dependent variables with names containing "60" used data within the evaluation period; i.e. a window of 60 seconds before and after each individual blast. As a control for individual variation in propensity to wake up, two variables used as covariates in the Overnight analyses were used again as covariates in these analyses, mdPctAwake_0blasts (for Awak60_Activity) and mdButtPushRateHr_0blasts (for Awak60_Button). Logistic regressions were performed using the SAS® LOGISTIC procedure. The option "SCALE =

PEARSON" was included in the model statement to implement Pearson's correction for overdispersion. Williams' method was not used to model overdispersion (as it was in the Overnight analyses), since this option could be used only with the events/trials syntax.

4 Results

Data Collection

Subject Demographics

The subject population was diverse (Table 2) and the average age and percentage of male/female participants was fairly representative of census data for the zip code that the study population was drawn from (Table 3). The census data is from year 2000.

Table 2. Subject factors.

Parameter	Mean	Standard Deviation	Min	Max
Age (years)	44.6	15.4	19	72
Distance From Firing Point (km)	5.4	2.9	1.8	8.9
Years in the Neighborhood (years)	10.9	8.8	1	29
Go to Bed Time (hh:mm)	22:31	1:13	19:12	2:45

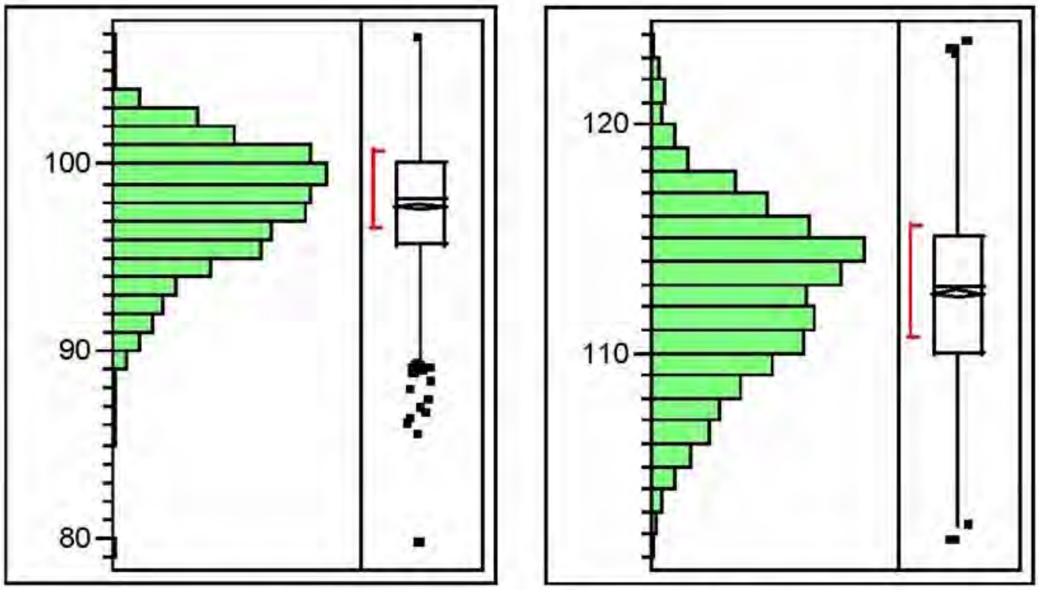
Table 3. Comparison of subject parameters and census data.

Age/Gender Parameter	Subjects	Census Data for Zip Code of Study Population (population 18-75 years of age)
Average Age	44.6	43.4
Percent Male	36%	50%
Percent Females	64%	50%

Distribution of Noise Levels

Figure 3 shows the distribution of blast events that were recorded when subjects were in bed, in terms of outdoor flat-weighted peak levels and the outdoor flat-weighted sound exposure levels. The metric level distributions of blast data collected for these metrics were approximately normal. Distributions of all stimulus metric levels tested are given in Appendix H. These data illustrate the large variance in received noise level that occurs even during a short time span. The variance results (for a given source)

from variation in the atmospheric propagation conditions, particularly wind and temperature structure, and can amount to a total range of as much as 50 dB (Schomer 1978)[12].



100.00%	maximum	106.7 dB
75.00%	quartile	100.0 dB
50.00%	median	98.1 dB
25.00%	quartile	95.7 dB
0.00%	minimum	79.7 dB

100.00%	maximum	123.6 dB
75.00%	quartile	115.1 dB
50.00%	median	112.9 dB
25.00%	quartile	110.0 dB
0.00%	minimum	101.6 dB

Figure 3. Outdoor flat-weighted SEL (left) and outdoor flat-weighted peak levels (right).

Morning Questionnaires

Subjects reported being awakened for longer periods and being more annoyed when they woke up from a blast event in comparison to other reasons as seen in Table 4.

[12] Schomer, P.D. and G.A. Luz, 1978. "Statistics of amplitude and spectrum of blasts propagated in the atmosphere," *Journal of the Acoustical Society of America*, 63(5), 1431-1443, May 1978.

Table 4. Comparison of reason for waking and annoyance.

Reason for Waking	Percentage of Responses	Median Number of Minutes Awake	Percent Not Very Annoyed	Percent Slightly Annoyed	Percent Moderately Annoyed	Percent Very Annoyed	Percent Extremely Annoyed
Bath-room	51	5	69	22	6	2.5	0.3
Don't Know	16	3	68	21	8.5	2.5	0
Blast Noise	10	10	10	43	25	12.5	10.

Overnight Analyses

The results of the overnight analyses are shown in Table 5, for analyses in which the effect of the explanatory variable was significant, controlling for the covariate effects. Salient features of these results were:

1. The covariates bedtime, age, sex and years resident had little or no effect on sleep bout duration or probability of awakening.
2. As the number of blast events increased during a night, the number of awakenings defined by button presses (BP) also increased ($p = 0.0075$). A covariate was used during this analysis to account for individual propensities of awakening, which was based on the median number of awakenings on nights that no blast events occurred. That is, the increase in awakenings was statistically adjusted for the number of awakenings that typically occurred for that individual on nights when there was no blast activity.
3. As the number of blast events increased during a night, the mean sleep bout time decreased ($p = 0.0365$). A covariate was used during this analysis to account for typical sleep bout lengths, which was based on the median mean sleep bout time on nights that no blast events occurred. This finding was expected given the finding described in the previous paragraph. If an increase in the number of blast events increased the number of awakenings, then one would also expect the length of time that subjects' consecutively slept to decrease.
4. As the reported openness of subjects' windows increased, the number of awakenings (AC) increased ($p = 0.0337$). Again, because of the covariate used to account for individual propensities of awakening on nights with no blast events, this finding is above and beyond the number of awakenings that typically occur on nights with no blast events.

Table 5. Overnight analyses with significant effects of the predictor variable of primary interest.

A)* Sleep Bout Duration					
Effect	DF	Estimate	Standard Error	Student's t	p-value
Intercept	1	97.34	81.91	1.19	0.2377
mdMean_sleep_bout_time_0blasts	1	0.87	0.13	6.53	0.0000
Bedtime8_hrs	1	-2.13	16.10	-0.13	0.8949
Age	1	0.20	1.08	0.18	0.8566
SexCode	1	29.53	47.97	0.62	0.5397
Yr_Resident	1	0.57	1.73	0.33	0.7418
BlastEvents	1	-1.87	0.88	-2.12	0.0365
B)* Voluntary Awakenings (Button Presses)					
Effect	DF	Estimate	Standard Error	χ^2	p-value
Intercept	1	-10.990	0.432	646.07	0.0000
mdButtPushRateHr_0bl	1	2.889	0.488	34.99	0.0000
Bedtime8_hrs	1	-0.026	0.090	0.08	0.7771
Age	1	0.003	0.006	0.19	0.6635
SexCode	1	0.374	0.183	4.17	0.0411
Yr_Resident	1	0.012	0.009	1.61	0.2052
BlastEvents	1	0.013	0.005	7.15	0.0075
Dispersion	1	0.224	0.066	_	_
C)* Involuntary Awakenings (Activity Counts)					
Effect	DF	Estimate	Standard Error	Wald χ^2	p-value
Intercept	1	-2.543	0.310	67.13	0.0000
mdPctAwake_0blasts	1	0.079	0.010	65.30	0.0000
Bedtime8_hrs	1	0.030	0.048	0.38	0.5397
Age	1	0.001	0.003	0.20	0.6511
SexCode	1	-0.105	0.090	1.36	0.2429
Yr_Resident	1	-0.001	0.005	0.05	0.8271
Response15	1	-0.141	0.066	4.51	0.0337

* A) Sleep bout duration, analyzed using general linear model. B) Voluntary awakenings, analyzed using negative binomial regression, with ln(Sleep Duration) used as an offset variable. C) Involuntary awakenings, analyzed using logistic regression analysis. “Dispersion” refers to William’s correction for overdispersion. See Table 2 for variable definitions.

Individual Blast Analyses

The Individual Blast Analyses show that awakenings strongly depend on noise event level in the beginning of the night or more specifically the time period 2100 – 2300; as the blast noise level increased during this time period, the probability of awakening increased. These results were significant for both definitions of awakenings (Figure 4 and Figure 5) for the following stimulus metrics: outdoor Flat-weighted peak and SEL, outdoor C-weighted SEL, and indoor Flat-weighted peak and SEL.

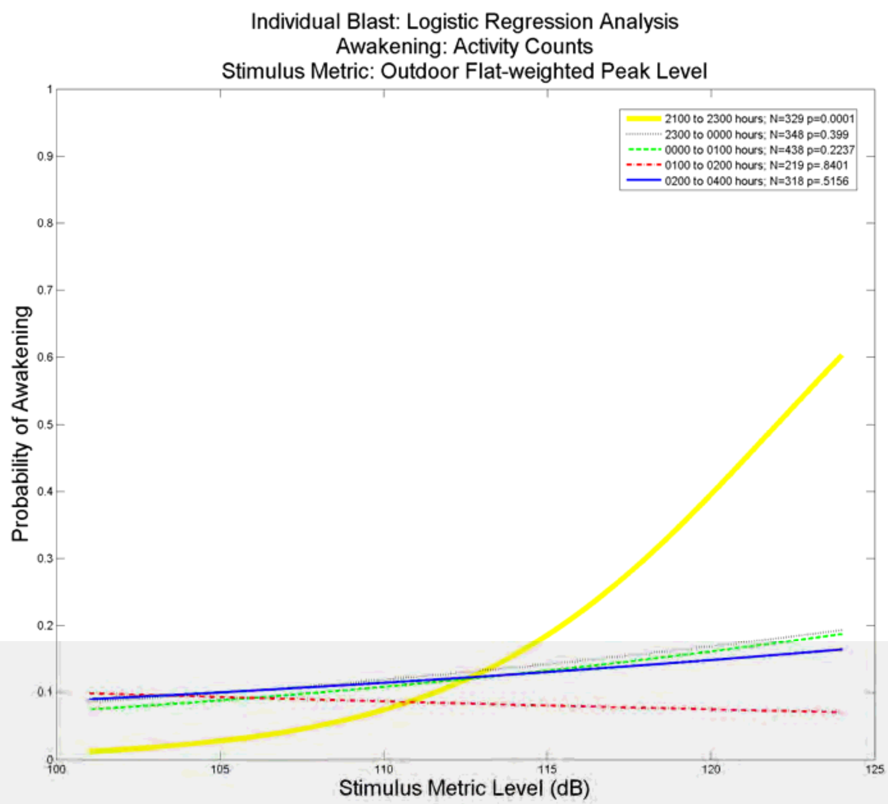


Figure 4. Logistic regression analysis of the probability of awakening from outdoor flat-weighted peak levels using AC definition of awakening for various time periods.

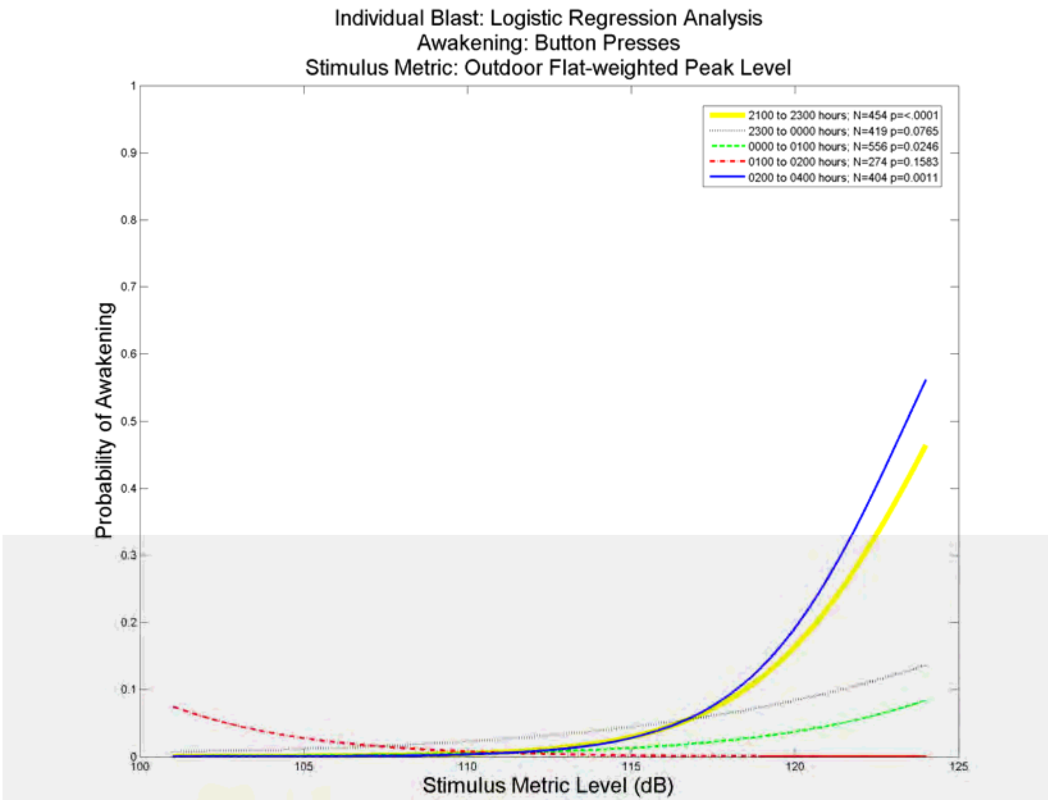


Figure 5. Logistic regression analysis of the probability of awakening from outdoor flat-weighted peak levels using BP definition of awakening for various time periods.

Conversely, awakening during the middle of the night (0000 - 0200) does not depend on event level. Even more significant is the fact that a given noise level produces a smaller percentage of awakenings after 2300 hours. It is also significant that higher noise levels, 100 - 104 dB Flat-weighted SEL and Flat-weighted peak levels greater than 115 dB, which are judged to carry a medium to high risk of noise complaints during the day (Pater[13]), only caused a very small percentage of the subjects to register a Button Press (Figure 5 and Figure 6) during this time period. No noise complaints were received during this study. The public was not informed that a sleep disturbance study was in progress.

[13] L. Pater, "Noise abatement program for explosive operations at NSWC/DL," *17th Explosives Safety Seminar,* Denver, CO, 1976.

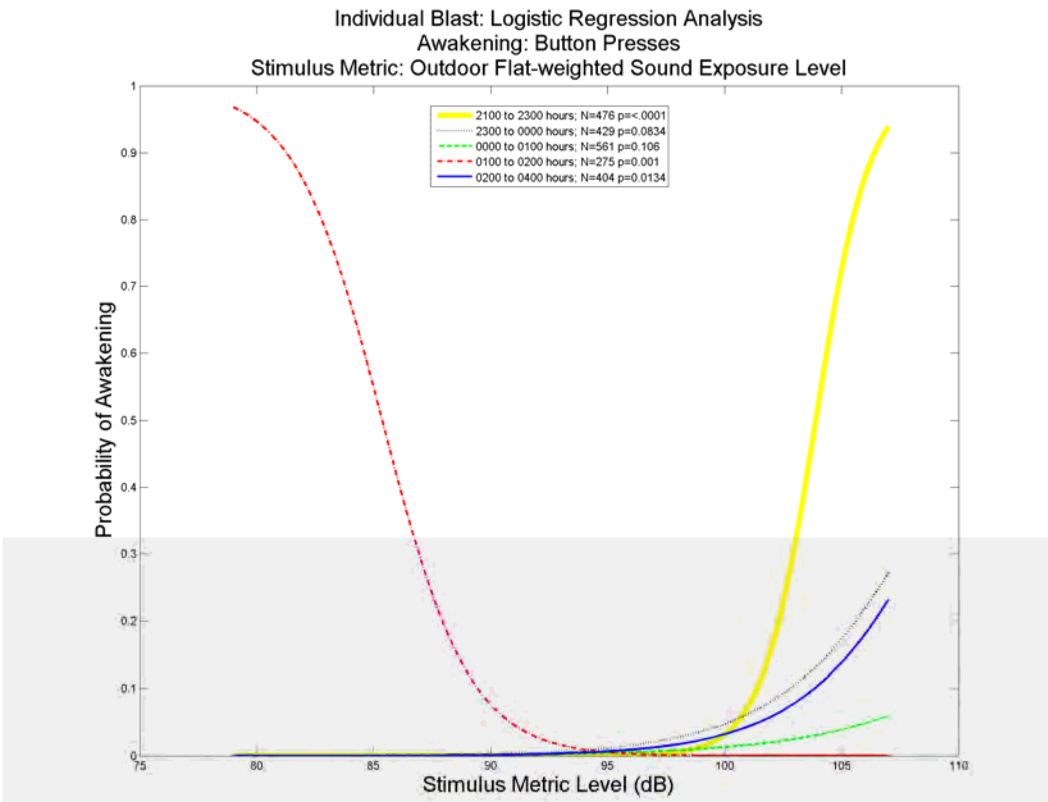


Figure 6. Logistic regression analysis of the probability of awakening from outdoor flat-weighted SEL using BP definition of awakening for various time periods.

Tables and plots of each individual blast analysis for both operational definitions of awakening (AC and BP) are given in Appendix I and Appendix J, respectively.

Awakenings defined by BP during the hours 2300 – 0000 were slightly dependent on noise event level, but to a lesser extent than during the 2100 – 2300 time period. This correlation was significant only for the outdoor and indoor flat-weighted SEL metrics (Figure 6 and Figure 7) of the noise level metrics tested.

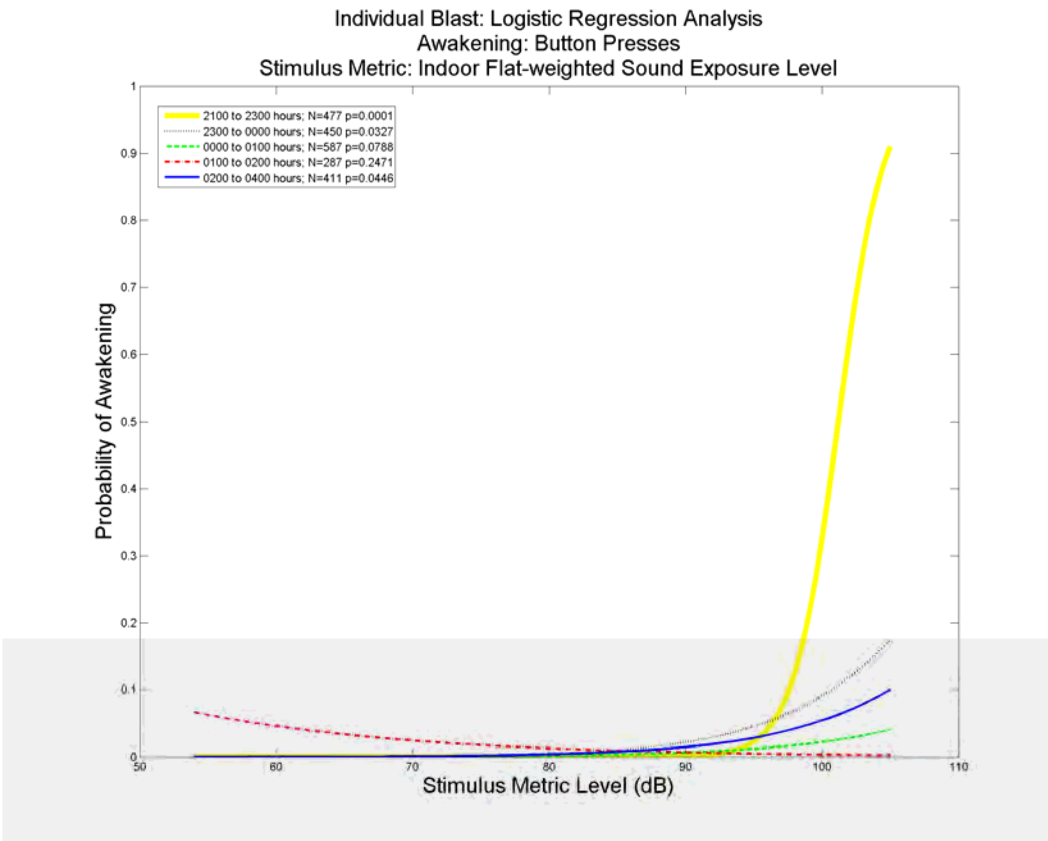


Figure 7. Logistic regression analysis of the probability of awakening from indoor flat-weighted SEL using BP definition of awakening for various time periods.

Awakenings defined by BP during the hours 0200 – 0400 were also dependent on stimulus noise metrics. However, the stimulus level metrics with most significant findings were different than those found significant for the beginning of the night. The outdoor C-weighted peak and SEL (Figure 8 and Figure 9), had the most significant findings during the time period 0200 – 0400, while the flat-weighted metrics (Figures 4 - 7) had the most significant findings during the beginning of the night (2100 – 2300). The following stimulus metrics had significant findings during this period and are ordered from most to least significant: outdoor C-weighted peak and SEL (Figures 8 and 9), outdoor flat-weighted peak level (Figure 5), and outdoor A-weighted peak and SEL (Figure 10 and Figure 11).

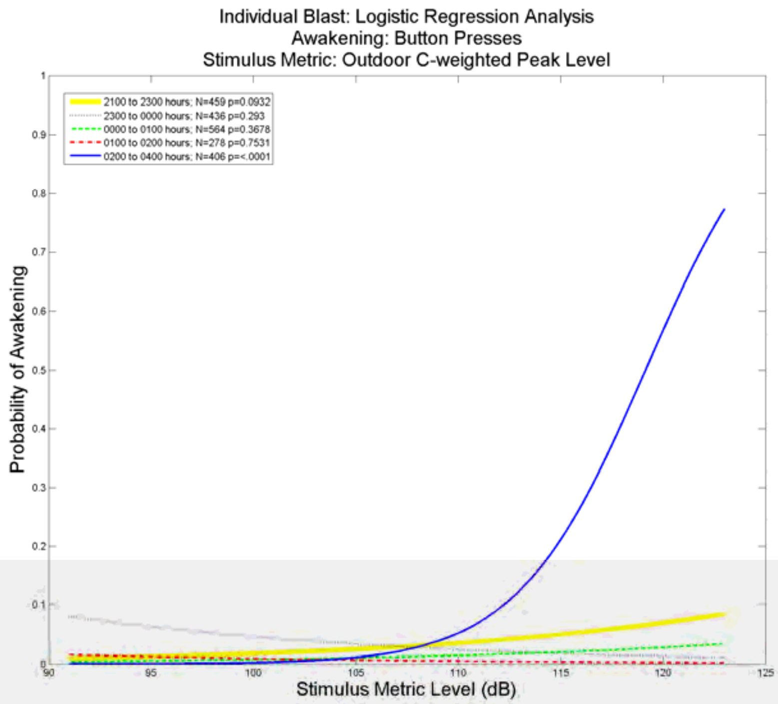


Figure 8. Logistic regression analysis of the probability of awakening from outdoor C-weighted peak levels using BP definition of awakening for various time periods.

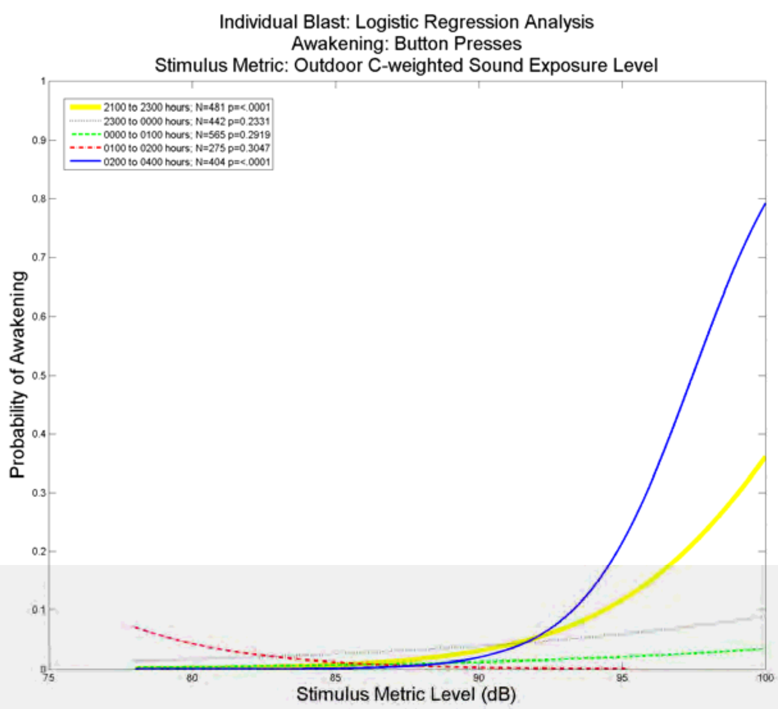


Figure 9. Logistic regression analysis of the probability of awakening from outdoor C-weighted SEL using BP definition of awakening for various time periods.

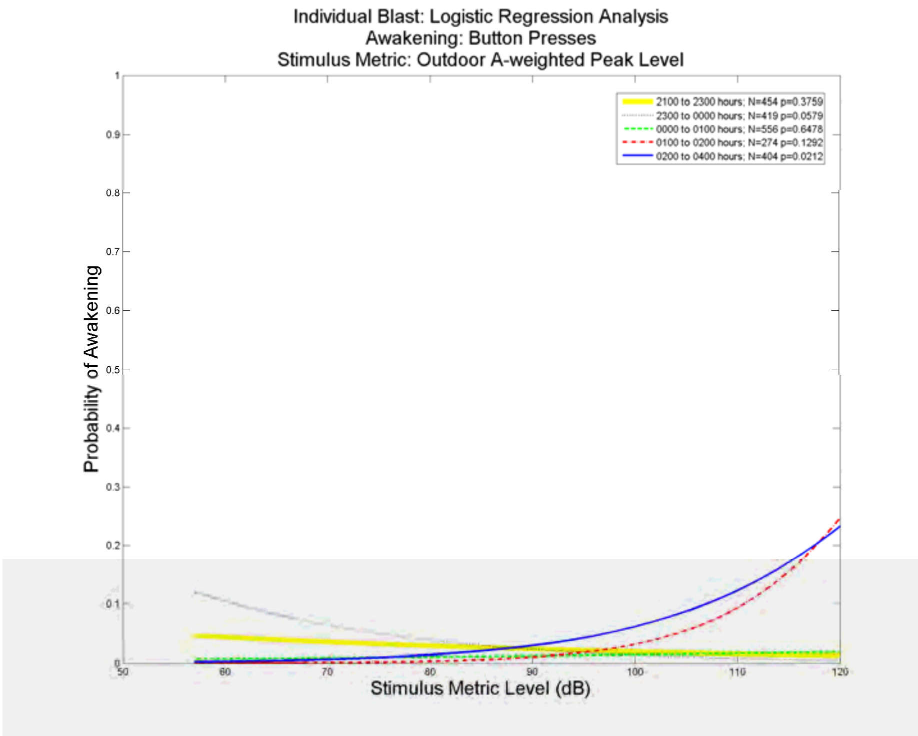


Figure 10. Logistic regression analysis of the probability of awakening from outdoor A-weighted peak levels using BP definition of awakening for various time periods.

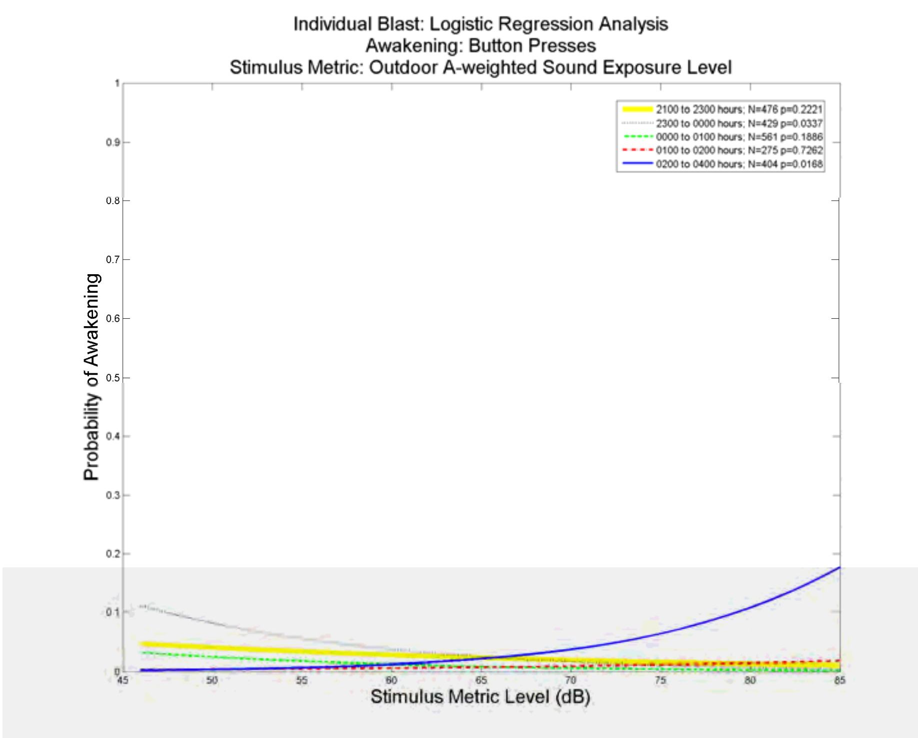


Figure 11 Logistic regression analysis of the probability of awakening from outdoor A-weighted SEL using BP definition of awakening for various time periods.

5 Discussion

Limitations Due To Sample Size

The sample sizes available for analysis did not permit inclusion of more than one independent variable and one covariate. As a result, separate analyses were run for each combination of independent variable and associated covariate. Recall, the covariate was used to control for individual variation in baseline levels of the developmental variable under consideration.

Outdoor and Indoor Stimulus Metrics

Military noise policy and guidance is primarily based on outdoor measurements because it is not feasible to accurately predict indoor levels. It is difficult to reliably predict the amount of attenuation each individual home provides to its residents. In general, the findings of this study did not uncover a good correlation between indoor stimulus metrics and awakenings. In order to accurately assess the relationship between indoor stimulus metrics and awakenings, ambient indoor noise levels, the level above the ambient noise level, and secondary noises caused by structural vibrations or bric-a-brac noise must be accurately measured. Fortunately, outdoor blast noise levels seems to reliably predict sleep disturbance.

Stimulus Metric Weighting Filters

During the beginning part of the night (2100 – 2300), the stimulus metrics that best predict the probability of awakening are the flat-weighted stimulus metrics; whereas the outdoor C-weighted metrics best predict the probability of awakenings during the later part of the night (0200 – 0400). These results could mean that different spectral frequencies are responsible for awakenings at different times of the night, or they could be an artifact of the relatively sparse BP dataset. For example, the findings for the beginning part of the night were significant for both operational definitions of awakening (AC and BP), but the findings for that later part of the night (0200 – 0400) were only significant for the analyses that used the BP definition of awakening.

Operational Definitions of "Awakening"

When comparing the results from the two definitions of awakening, it can be observed that awakening defined by activity counts (AC) is a more sensitive measure of awakening in comparison to awakenings by button presses (BP). As shown in Figure 12, the BP regression curves, with exception of the 0200 – 0400 data, have a steeper slope than the AC regression curves. The steepness of the slope may be due to the greater precision in measurement of the button press data in comparison to activity count data, or may be artificially due to the sparseness of button press data. However, the general similarity of the curves for both definitions of awakenings suggests that both methods were meaningfully measuring the same effect.

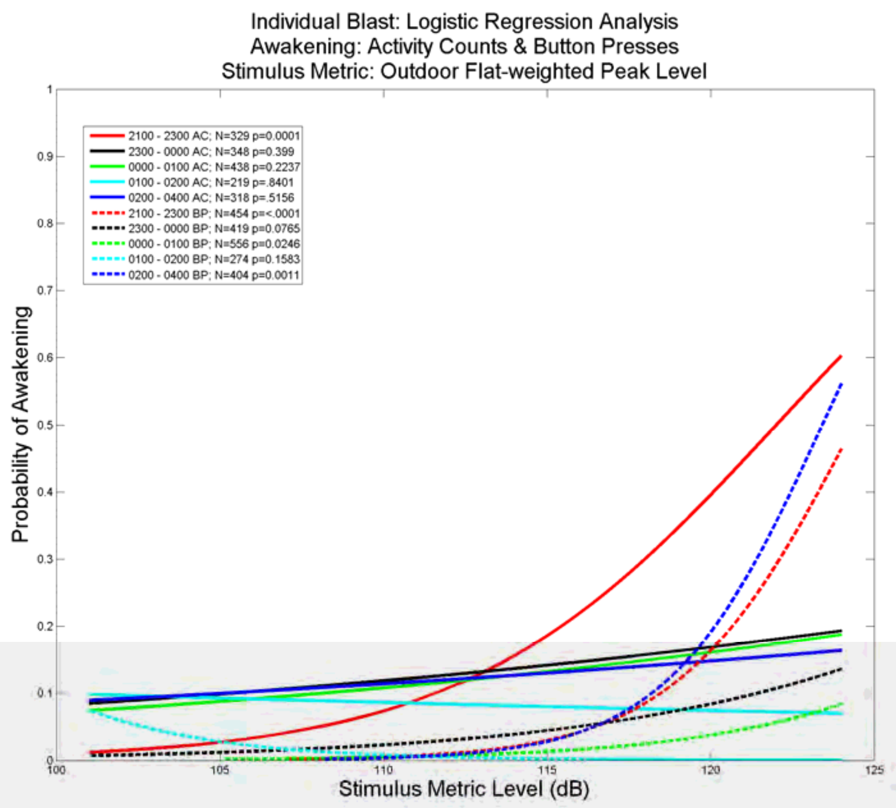


Figure 12. Logistic regression analysis of the probability of awakening from outdoor flat-weighted peak level comparing the BP and AC definitions of awakening for various time periods.

Choice of criteria for awakening is an important consideration in sleep studies. Awakening defined by button presses definitively reflects the conscious waking state of the subject. However, the method is dependent on whether the sleeping person remembers to press the button when awakened, which in turn is dependent on whether the person is consciously awake. Another confounding factor is whether the task of pressing the button upon waking influences the subject's normal sleeping habits. The pressing of the button could cause the subject to reach a state of consciousness that wouldn't normally be reached, and may make it harder for the person to fall back asleep.

The actimeter activity count method of awakening is a less precisely interpretable method of awakening, because it is never fully known whether the person was actually awake or just happened to move in his/her sleep. Also, this criterion for awaking is dependent on a threshold level that is somewhat arbitrary. For example, for this study a subject was considered awake if the activity count was above a threshold value of 40 and considered to be asleep if below 40. As a result there is an inherent uncertainty of sleep state around the threshold level. On the other hand, the actimeter activity count method of awakening is less invasive and has no dependence on human consciousness, measuring the degree to which sleep was restful or unrestful. Sleep research conducted solely using the activity count awakening method reduces dependence of the results on a subjects' conscious self-assessment, which is by definition insensitive to subliminal states of unrest.

Findings in Comparison to Pilot Study

The findings from this current study concur with the findings from the pilot study, which showed that awakenings were dependent on the time and level of blast events. In particular, it was found that awakenings were positively associated with stimulus metric level during the beginning part of the night (2100 to 2300). However, during the middle part of the night (0000 to 0200), there were fewer awakenings and little to no dependence on the decibel level of the blast event.

In both studies two definitions of awakenings were tested. Each definition gave similar results, except awakening based on AC seemed to be a more sensitive measure than awakening based on BP. That is, there were more awakenings calculated from activity counts than button presses. The simi-

larity of the results might suggest that either method is suitable for future research.

Findings in Comparison to Complaint Risk Criteria

The two most common criteria used to measure human response to blast noise are complaints and annoyance. At night, another useful way to measure community response to blast noise is through sleep awakenings and disturbances. During the day, Pater's complaint risk criteria[14], is often used at DoD installations to judge risk of receiving noise complaints. Pater's complaint risk criteria are given in Appendix K. During the beginning and later part of the night (2100 to 2300 and 0200 to 0400), the threshold values of the probability of awakening and complaint risk criteria are very similar as shown in Figure 12; i.e. if the level of an outdoor blast event is less than a un-weighted peak level of 115 dB, there is a low probability of awakening and a low risk of complaints. As the decibel level increases above 115 dB, the probability of awakening and complaint risk increase.

[14] L. Pater, "Noise abatement program for explosive operations at NSWC/DL," *17th Explosives Safety Seminar,* Denver, CO, 1976.

6 Conclusions

Blast Noise Negatively Affects Local Residents

The main conclusion to be drawn from this study is that nighttime blast noise negatively affects local residents while sleeping or trying to fall asleep. The overnight logistic regression analysis found that as the number of blast events increased during a night, the number of awakenings (button presses) increased. The individual blast analyses also found that the time of the blast event significantly affected subject awakenings. In the beginning of the night (2100 to 2300) the metric level had an effect on the number of awakenings or the probability of awakening, whereas the dependence on awakening on metric level was not apparent in the middle part of the night (0000 to 0200). For all stimulus metric levels measured, the probability of sleep disturbance was smaller in the middle of the night compared to the evening hours before midnight.

As more people move closer to military installations, encroachment issues such nighttime training noise have the potential to cause further negative impact on residents living near military installations. In 2002, the United States General Accounting Office reported that, "Urban growth near 80 percent of its [DoD's] installations exceeds the national average."[15]

Current Nighttime Training Restrictions and Recommendations

Military installations clearly recognize that both day and night training are required to enable realistic rehearsal with all weapons to ensure combat proficiency and to minimize loss of life. However, to preserve training capability, installations also endeavor to minimize community noise disturbance and resulting negative public reaction. To this end, installations self impose firing curfews that typically stipulate that noise training should be completed before midnight. The results of this research project clearly and strongly indicate that community disturbance is more effectively reduced by conducting training between 0000 and 0200 hours, and avoiding noisy training during the evening hours before midnight.

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15 Government Accounting Office (GAO), *Military Training: DoD lacks a comprehensive plan to manage encroachment on training ranges*, GAO-02-614, Washington, D.C., 45 pp.

Recommendations for Future Work

The results of this study suggest that postponing nighttime firing until after midnight, or at least after 2300, when the majority of residents have already fallen asleep, could potentially minimize the negative impact of blast noise on local residents. These findings are statistically significant for the present study population, but they should be investigated further before accepting their validity as general. This study demonstrated the practicality and importance of conducting this type of field research with actual military blast stimuli and with subjects sleeping in their own beds. One of the issues with this study was the sparsity of data. It is therefore recommended that a future, larger scale effort should include a random sample of several communities exposed to a large number of nighttime blast noise events over a longer period of time to determine to what extent the findings from this study can be applied to all communities surrounding installations.

Future work should explore the effect of ambient noise level, the level of noise events above the ambient noise level, and 1/3 octave band level on awakening for various time periods. Time periods should also include the end of the night hours (0400 to 0600); no blast events occurred during this time period in this study.

Appendix A: Sleep Study Participant Form

IF YOU ARE INTERESTED IN PARTICIPATING IN THE STUDY, PLEASE COMPLETE THIS FORM AND RETURN IN THE POSTAGE-PAID ENVELOPE PROVIDED

Sleep Study Participant Form

Last Name________________ First Name______________ Email Address______________

Address________________________________City_____________State____Zip__________

Daytime Phone Number______________ Evening Phone Number______________ Age___

Please choose the way you would like to be reached: Email Phone-Day Phone-Evening

How long have you lived in the neighborhood? ___________________________________

What time do you usually go to bed at night? _____________________________________

What time do you usually get up in the morning? __________________________________

Do you have a hard time falling asleep at night?	Yes	No
Do you have normal hearing?	Yes	No
Do you have a sleep disorder?	Yes	No
Are you taking any medication that affects sleep?	Yes	No
Do you think it will bother you to wear a wristwatch to bed?	Yes	No
Have you ever heard noises from (Military Installation) at night?	Yes	No
Have you ever been awakened by noise(s) from (Military Installation)?	Yes	No

Appendix B: Letter to Subjects

Dear (Subject),

Thank you for participating in the (installation name) Sleep Study Project. You are currently scheduled to participate starting September 21, 2004 and ending October 4, 2004. The project manager and team are scheduled to stop by on the following dates and times:

Set Up Equipment 9/21/2004 @ 9:00 A.M.

Check Equipment 9/24/2004 @ 8:30 A.M., 9/26 @ 4:30 P.M., 9/29/ @5:00 P.M.

Take Down Equipment 10/04/2004 @ 3:00 P.M.

Please expect the project manager and team to arrive anytime one hour before or after your scheduled time. Please contact (project manager) at 1-800-###-#### if you have any questions or conflicts with the scheduled dates and times.

As discussed during the initial interview, payment for participation is $15.00 per night. You will be paid after the study is completed, which is scheduled to end on November 1, 2004. All money will be paid through (Temp Agency). Please contact (Temp Agency) if you have any questions regarding the payment process.

Sincerely,

(Temp Agency)

Appendix C: Sleep Study Instructions

Sleep Study Instructions

Questions

If you have any questions, please call (Project Leader) at (XXX)XXX-XXXX or (800)XXX-XXXX, or send an email to (Project Leader's email address). Please contact immediately if your house loses power or if anything happens to the equipment. Please call at any time of the day or night if you have any questions or concerns.

Instructions

1. Before you go to bed, place the Minimitter on the wrist of your choice. You MUST wear the Minimitter on the SAME WRIST every night.

2. Firmly press the button on the Minimitter once just before you get into bed. It is OK if you read or watch TV in bed before you fall asleep.

3. Press the button once every time you wake up throughout the night, no matter what the reason is. If you forget to press the button, DO NOT press the button twice the next time you wake up. In the morning you will have the opportunity to report how many times you woke up, how many times you pressed the button, and how long you were awake each time.

4. As soon as you get out of bed in the morning, press the button once and take off the Minimitter. Do not wear the Minimitter while napping during the day.

5. Store the Minimitter in a safe place, but keep it visible so you remember to wear it the following night.

6. Answer the Morning Questionnaire each morning.

7. Wear the Minimitter each night throughout the study

CAUTION: The Minimitter wrist device is an expensive piece of equipment and should be properly taken care of. DO NOT get the Minimitter WET.

Appendix D: Morning Questionnaire

Morning Questionnaire (Circle the best answer)

Name__________________________________ **Today's Date**___/___/_____ **M# on Folder**________

Question 1: How tired were you yesterday during the day?

Response	Response Number
Not tired at all	1
Slightly tired	2
Moderately tired	3
Very tired	4
Extremely tired	5

Question 2: How stressful was your day yesterday?

Response	Response Number
Not stressful at all	1
Slightly stressful	2
Moderately stressful	3
Very stressful	4
Extremely stressful	5

Question 3: How tired were you last night before you went to bed?

Response	Response Number
Not at all tired	1
Slightly tired	2
Moderately tired	3
Very tired	4
Extremely tired	5

Question 4: How long did it take you to fall asleep last night?

Response	Response Number
0-5 minutes	1
5-15 minutes	2
15-30 minutes	3
30-60 minutes	4
Over 60 minutes	5

Question 5: How well did you sleep last night?

Response	Response Number
Not well at all	1
Slightly well	2
Moderately well	3
Very well	4
Extremely well	5

Question 6: How well do you normally sleep?

Response	Response Number
Not well at all	1
Slightly well	2
Moderately well	3
Very well	4
Extremely well	5

Question 7: How tired do you feel this morning?

Response	Response Number
Not at all tired	1
Slightly tired	2
Moderately tired	3
Very tired	4
Extremely tired	5

Question 8: How irritable do you feel this morning?

Response	Response Number
Not at all irritable	1
Slightly irritable	2
Moderately irritable	3
Very irritable	4
Extremely irritable	5

Question 9: How physically active were you yesterday?

Response	Response Number
Not at all active	1
Slightly active	2
Moderately active	3
Very active	4
Extremely active	5

Question 10: Did you take a nap yesterday?

Response	Response Number
Yes, over 2 hours	1
Yes, between 1-2 hours	2
Yes, between 30-60 minutes	3
Yes, less than 30 minutes	4
No	5

Question 11: Did you have alcohol last night?	
Response	Response Number
Yes, a lot	1
Yes, a moderate amount	2
Yes, but only a little	3
No	4

Question 12: Did you have caffeine last night?	
Response	Response Number
Yes, a lot	1
Yes, a moderate amount	2
Yes, but only a little	3
No	4

Question 13: Did you take sleeping pills or other medication yesterday?	
Response	Response Number
Yes	1
No	2
If yes, please specify:	

Question 14: Do you think the alcohol, caffeine, sleeping pills, or medication affected your sleep?	
Response	Response Number
Yes	1
No	2
Not Applicable	3

Question 15: Describe the position of your bedroom windows last night?	
Response	Response Number
Wide open	1
Half-way open	2
Slightly open	3
Closed	4

Question 16: How would you describe your health today?	
Response	Response Number
Poor health	1
OK health	2
Good health	3
Excellent health	4

Question 17: Did you remember to press the button on the Minimitter when you got into bed?	
Response	Response Number
Yes	1
No	2

Question 18: Did you press the button on the Minimitter when you got out of bed?	
Response	Response Number
Yes	1
No	2

Question 19: What time did you get into bed last night?
Enter Time Below

Question 20: What time did you wake up this morning?
Enter Time Below

Question 21: What time did you get out of bed?
Enter Time Below

Question 22: How many times do you remember waking up last night?
Enter Number of Times Below

Appendix E: Variables Used in Overnight Analyses

	Variable	Definition
Dependent Variables	Mean_sleep_bout_time	Mean duration of sleep bouts (sec)
	Mean_wake_bout_time	Mean duration of waking bouts (sec)
	SlpDuration	Total time asleep (bedtime to wake-up time) (sec)
	Awakenings/n_awakes (trials/events)	Number of seconds spent awake/total seconds in bed
	ButtonPushes	Total number of button pushes recorded
	Response5	Response to Question 5
	Bedtime8_hrs	Time subject went to bed
Baseline Values	mdMean_sleep_bout_time_0blasts	Median of the nightly mean of dependent variable for nights with 0 blasts.
	mdMean_wake_bout_time_0blasts	"
	mdSlpDuration_0blasts	"
	mdPctAwake_0blasts	Median of the nightly mean % of time window spent awake for nights with 0 blasts.
	mdButtPushRateHr_0blasts	Median of the nightly mean hourly button push rate for nights with 0 blasts
	mdResponse5_0blasts	"
	mdBedtime8_hrs_0blasts	"
Covariates	Bedtime8_hrs	Bedime expressed as number of hours after 20:00
	Age	Subject's age in years
	SexCode	0 = male, 1 = female
	Yr_Resident	Years subject had been resident at that location
Independent Variables	BlastEvents	Total number of blast events within time window
	Mean_Outdoor_LAPeak	Mean value for the specified acoustic index, within the time window
	Mean_Outdoor_LCPeak	"
	Mean_Outdoor_LZPeak	"
	Mean_Outdoor_LAE	"
	Mean_Outdoor_LCE	"
	Mean_Outdoor_LZE	"
	Response1	Response to questionnaire Question 1
	Response2	Response to questionnaire Question 2
	Response3	Response to questionnaire Question 3
	Response4	Response to questionnaire Question 4
	Response6	Response to questionnaire Question 6
	Response9	Response to questionnaire Question 9
	Response10	Response to questionnaire Question 10
	Response11	Response to questionnaire Question 11
	Response12	Response to questionnaire Question 12
	Response15	Response to questionnaire Question 15
	Mean_Factor1	Mean value of Factor 1 from PCA.
	Mean_Factor2	Mean value of Factor 2 from PCA.
	Mean_Factor3	Mean value of Factor 3 from PCA.
	Mean_Factor4	Mean value of Factor 4 from PCA.
	Mean_Factor5	Mean value of Factor 5 from PCA.

Appendix F: Statistical Models Applied in Overnight Analyses

See Appendix E for a description of the variables used. Each line describes a separate set of analyses, one for each independent variable described in Appendix E.

Model	Time Window	Dependent Variable	Undisturbed Baseline Value	Covariate 1	Covariate 2	Covariate 3	Covariate 4	Independent Variable
General Linear Model	Time In Bed	Mean_sleep_bout_time	mdMean_sleep_bout_time_0blasts	Bedtime8_hrs	Age	SexCode	Yr_Resident	variable
General Linear Model	Time In Bed	Mean_wake_bout_time	mdMean_wake_bout_time_0blasts	Bedtime8_hrs	Age	SexCode	Yr_Resident	variable
General Linear Model	Time In Bed	SlpDuration	mdSlpDuration_0blasts	Bedtime8_hrs	Age	SexCode	Yr_Resident	variable
Logistic Regression	Time In Bed	Awakenings/n_awakes	mdPctAwake_0blasts	Bedtime8_hrs	Age	SexCode	Yr_Resident	variable
Negative Binomial Regression	Time In Bed	ButtonPushes	mdButtPushRateHr_0blasts	Bedtime8_hrs	Age	SexCode	Yr_Resident	variable
General Linear Model	Time In Bed	Response5	mdResponse5_0blasts	Bedtime8_hrs	Age	SexCode	Yr_Resident	variable
General Linear Model	Evening (21:00 to 23:00)	Bedtime8_hrs	mdBedtime_0blasts		Age	SexCode	Yr_Resident	variable

Appendix G: Statistical Models Applied in Individual Blasts Analyses

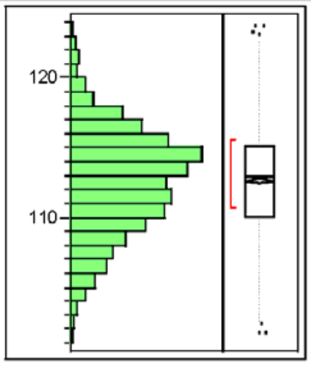
See Appendix E for definitions of the covariates. Each line describes a separate set of logistic regression analyses, one for each independent variable (see text for list of independent variables used).

Time Window	Pre-Blast Wakefulness Criteria	Dependent Variable	Covariate	Independent Variable
T1: 09:00-11:00	Activity	Awak60_Activity	mdPctAwake_0blasts	variable
T1: 09:00-11:00	Button	Awak60_Button	mdButtPushRateHr_0blasts	variable
T2: 11:00-12:00	Activity	Awak60_Activity	mdPctAwake_0blasts	variable
T2: 11:00-12:00	Button	Awak60_Button	mdButtPushRateHr_0blasts	variable
T3: 12:00-01:00	Activity	Awak60_Activity	mdPctAwake_0blasts	variable
T3: 12:00-01:00	Button	Awak60_Button	mdButtPushRateHr_0blasts	variable
T4: 01:00-02:00	Activity	Awak60_Activity	mdPctAwake_0blasts	variable
T4: 01:00-02:00	Button	Awak60_Button	mdButtPushRateHr_0blasts	variable
T5: 02:00-04:00	Activity	Awak60_Activity	mdPctAwake_0blasts	variable
T5: 02:00-04:00	Button	Awak60_Button	mdButtPushRateHr_0blasts	variable

Appendix H: Metric Level Distributions

Distributions

Outdoor Flat-Weighted Peak Level (dB)



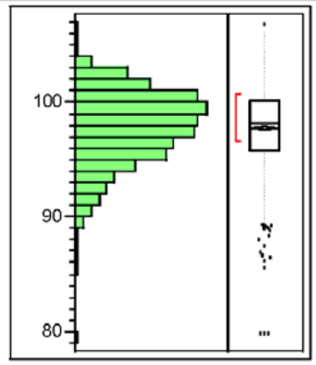
Quantiles

100.0%	maximum	123.60
99.5%		122.40
97.5%		119.60
90.0%		117.00
75.0%	quartile	115.10
50.0%	median	112.90
25.0%	quartile	110.00
10.0%		107.60
2.5%		104.90
0.5%		102.90
0.0%	minimum	101.60

Moments

Mean	112.54843
Std Dev	3.7371252
Std Err Mean	0.0803358
upper 95% Mean	112.70597
lower 95% Mean	112.39089
N	2164

Outdoor Flat-Weighted Sound Exposure Level (dB)



Quantiles

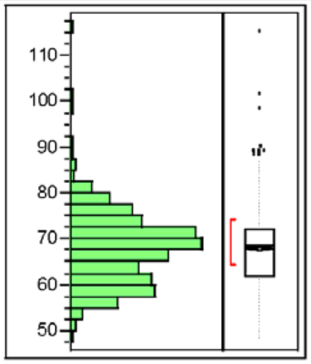
100.0%	maximum	106.70
99.5%		103.70
97.5%		102.90
90.0%		101.50
75.0%	quartile	100.00
50.0%	median	98.10
25.0%	quartile	95.70
10.0%		93.30
2.5%		90.60
0.5%		88.21
0.0%	minimum	79.70

Moments

Mean	97.709219
Std Dev	3.2440966
Std Err Mean	0.069133
upper 95% Mean	97.844792
lower 95% Mean	97.573646
N	2202

Distributions

Indoor A-Weighted Peak Level (dB)



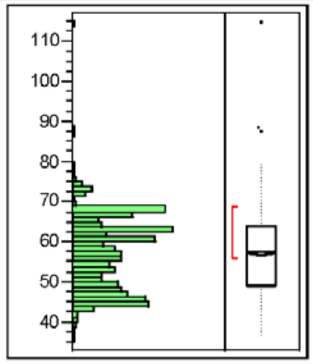
Quantiles

100.0%	maximum	115.00
99.5%		88.00
97.5%		81.00
90.0%		77.00
75.0%	quartile	72.03
50.0%	median	68.40
25.0%	quartile	61.80
10.0%		58.10
2.5%		55.00
0.5%		51.89
0.0%	minimum	48.00

Moments

Mean	67.649426
Std Dev	7.2370002
Std Err Mean	0.1583016
upper 95% Mean	67.959871
lower 95% Mean	67.33898
N	2090

Indoor A-Weighted Sound Exposure Level (dB)



Quantiles

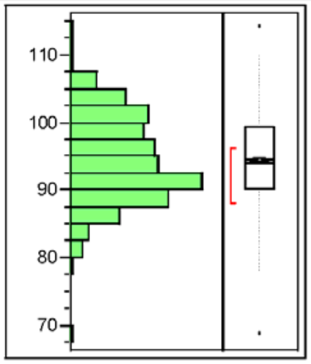
100.0%	maximum	114.30
99.5%		77.29
97.5%		73.41
90.0%		67.80
75.0%	quartile	63.50
50.0%	median	57.36
25.0%	quartile	48.63
10.0%		44.96
2.5%		43.23
0.5%		39.57
0.0%	minimum	35.62

Moments

Mean	56.923485
Std Dev	8.995604
Std Err Mean	0.193914
upper 95% Mean	57.303764
lower 95% Mean	56.543207
N	2152

Distributions

Indoor C-Weighted Peak Level (dB)



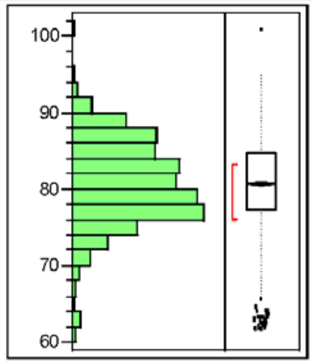
Quantiles

100.0%	maximum	114.00
99.5%		107.00
97.5%		105.60
90.0%		103.00
75.0%	quartile	99.20
50.0%	median	93.80
25.0%	quartile	90.00
10.0%		87.00
2.5%		83.00
0.5%		80.80
0.0%	minimum	68.60

Moments

Mean	94.393094
Std Dev	6.080186
Std Err Mean	0.1296005
upper 95% Mean	94.647246
lower 95% Mean	94.138942
N	2201

Indoor C-Weighted Sound Exposure Level (dB)



Quantiles

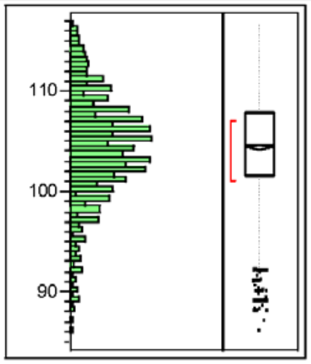
100.0%	maximum	100.70
99.5%		92.23
97.5%		90.49
90.0%		87.83
75.0%	quartile	84.58
50.0%	median	80.51
25.0%	quartile	77.15
10.0%		74.25
2.5%		69.33
0.5%		61.98
0.0%	minimum	61.42

Moments

Mean	80.629513
Std Dev	5.5528574
Std Err Mean	0.1167278
upper 95% Mean	80.858418
lower 95% Mean	80.400608
N	2263

Distributions

Indoor Flat-Weighted Peak Level (dB)



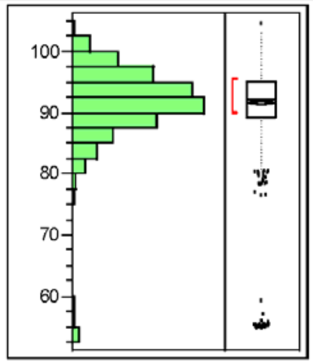
Quantiles

100.0%	maximum	116.80
99.5%		116.01
97.5%		114.23
90.0%		111.00
75.0%	quartile	107.75
50.0%	median	104.50
25.0%	quartile	101.50
10.0%		97.66
2.5%		92.00
0.5%		88.97
0.0%	minimum	86.00

Moments

Mean	104.31684
Std Dev	5.319666
Std Err Mean	0.1138043
upper 95% Mean	104.54002
lower 95% Mean	104.09367
N	2185

Indoor Flat-Weighted Sound Exposure Level (dB)



Quantiles

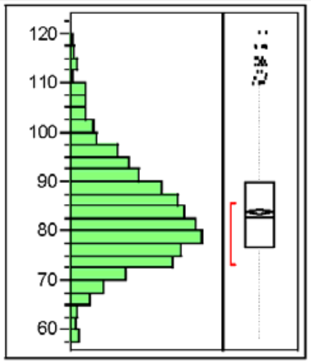
100.0%	maximum	104.44
99.5%		102.08
97.5%		100.65
90.0%		97.92
75.0%	quartile	95.05
50.0%	median	92.11
25.0%	quartile	89.16
10.0%		85.47
2.5%		79.95
0.5%		54.84
0.0%	minimum	54.52

Moments

Mean	91.407032
Std Dev	6.6492235
Std Err Mean	0.1395898
upper 95% Mean	91.680769
lower 95% Mean	91.133295
N	2269

Distributions

Outdoor A-Weighted Peak Level (dB)



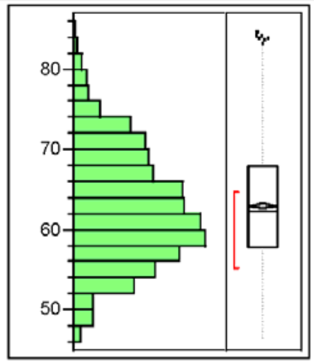
Quantiles

100.0%	maximum	119.90
99.5%		115.09
97.5%		107.69
90.0%		97.20
75.0%	quartile	89.60
50.0%	median	82.40
25.0%	quartile	76.40
10.0%		72.00
2.5%		66.24
0.5%		59.48
0.0%	minimum	57.70

Moments

Mean	83.61756
Std Dev	10.260056
Std Err Mean	0.2205571
upper 95% Mean	84.050086
lower 95% Mean	83.185034
N	2164

Outdoor A-Weighted Sound Exposure Level (dB)



Quantiles

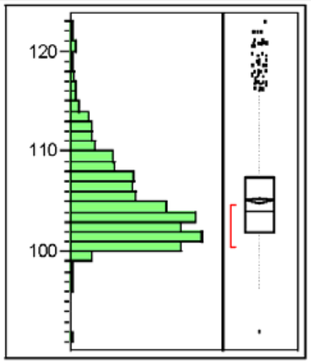
100.0%	maximum	84.500
99.5%		82.891
97.5%		78.000
90.0%		72.200
75.0%	quartile	67.800
50.0%	median	62.100
25.0%	quartile	57.700
10.0%		54.000
2.5%		49.915
0.5%		47.500
0.0%	minimum	46.200

Moments

Mean	62.794914
Std Dev	7.0846912
Std Err Mean	0.1509775
upper 95% Mean	63.090987
lower 95% Mean	62.49884
N	2202

Distributions

Outdoor C-Weighted Peak Level (dB)



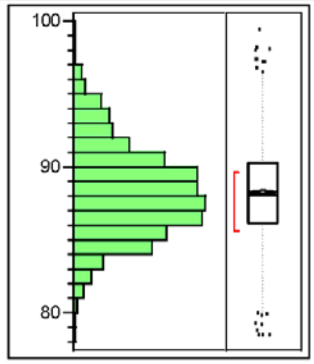
Quantiles

100.0%	maximum	122.80
99.5%		120.70
97.5%		115.89
90.0%		110.90
75.0%	quartile	107.40
50.0%	median	103.90
25.0%	quartile	101.90
10.0%		100.60
2.5%		99.80
0.5%		97.50
0.0%	minimum	91.90

Moments

Mean	104.99355
Std Dev	4.2728448
Std Err Mean	0.0910974
upper 95% Mean	105.17219
lower 95% Mean	104.8149
N	2200

Outdoor C-Weighted Sound Exposure Level (dB)



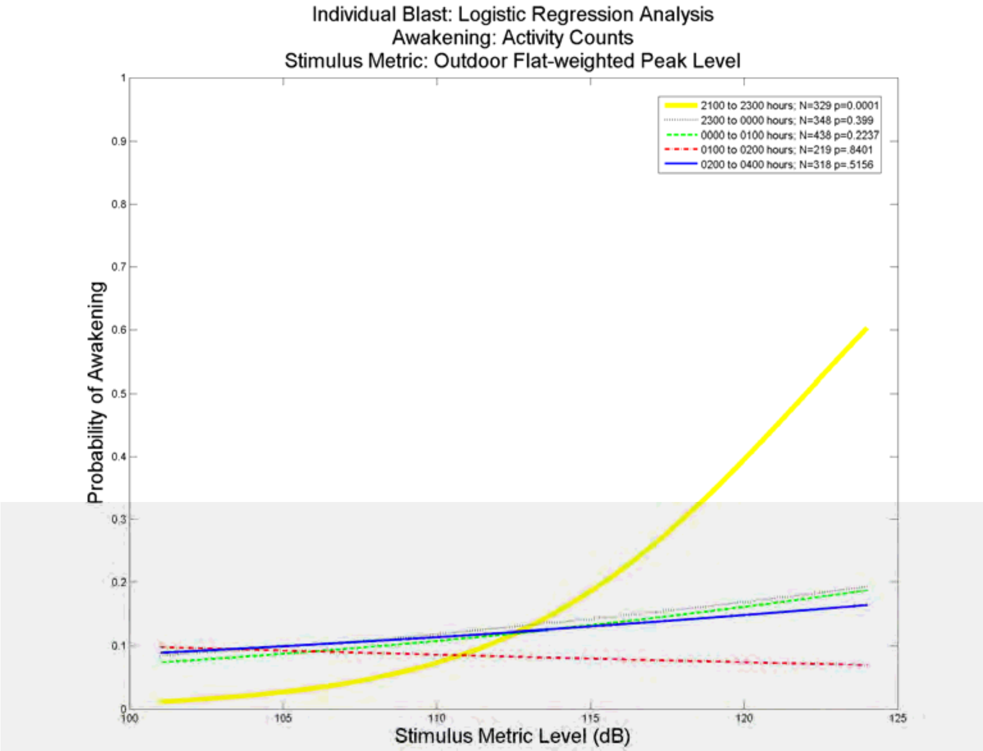
Quantiles

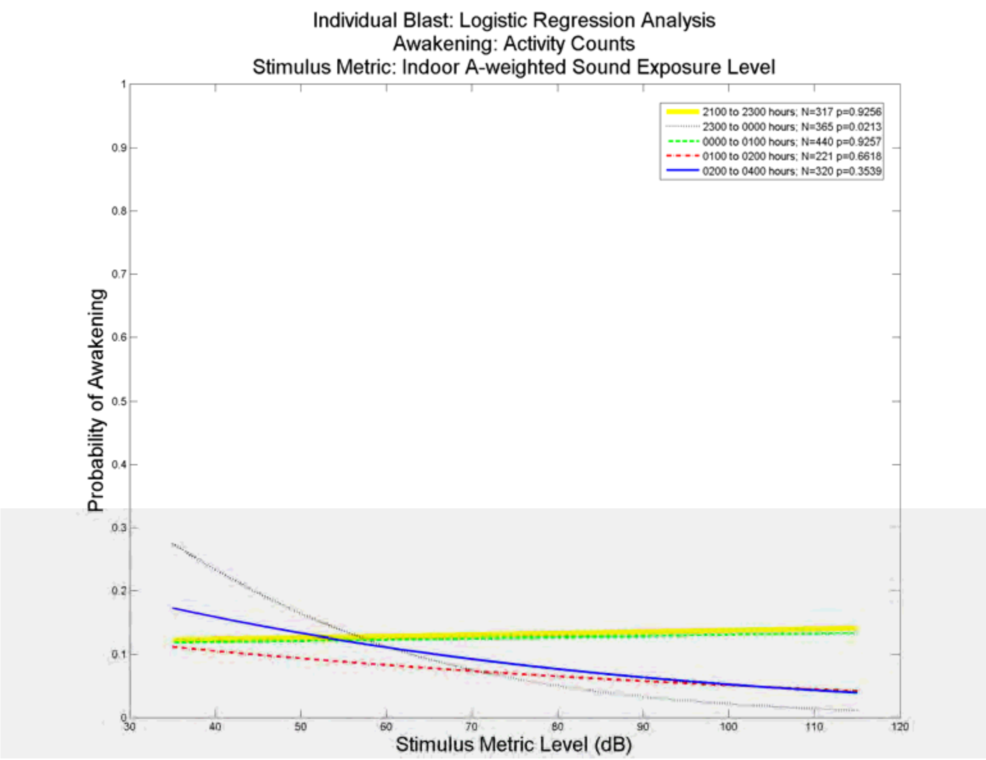
100.0%	maximum	99.300
99.5%		96.300
97.5%		95.013
90.0%		92.600
75.0%	quartile	90.200
50.0%	median	88.000
25.0%	quartile	86.100
10.0%		84.500
2.5%		82.300
0.5%		80.200
0.0%	minimum	78.400

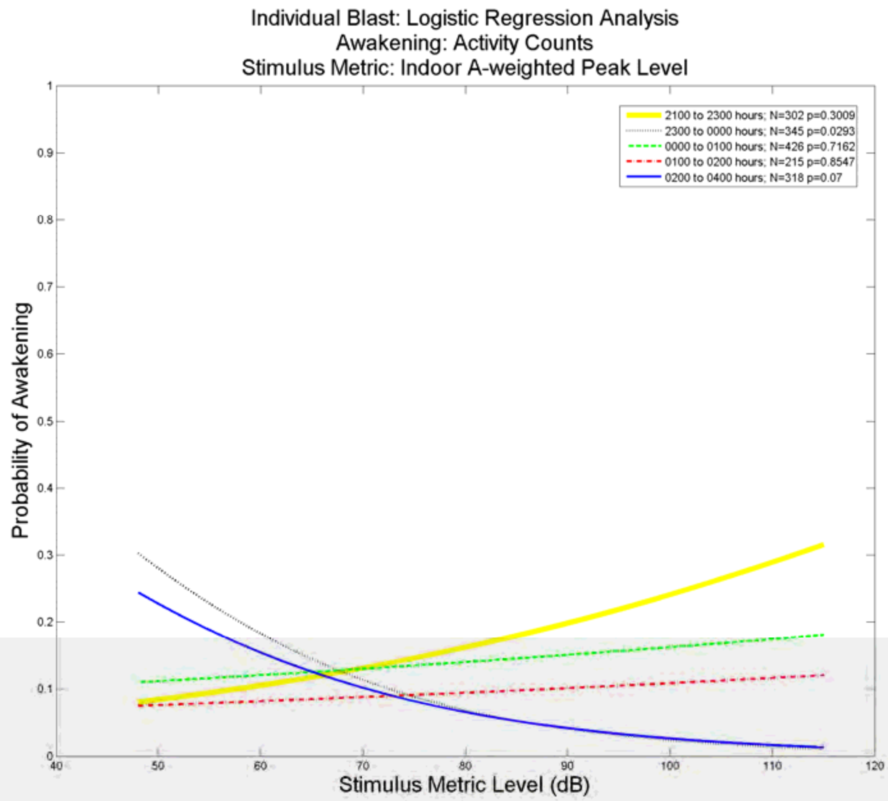
Moments

Mean	88.243255
Std Dev	3.1644377
Std Err Mean	0.067101
upper 95% Mean	88.374843
lower 95% Mean	88.111668
N	2224

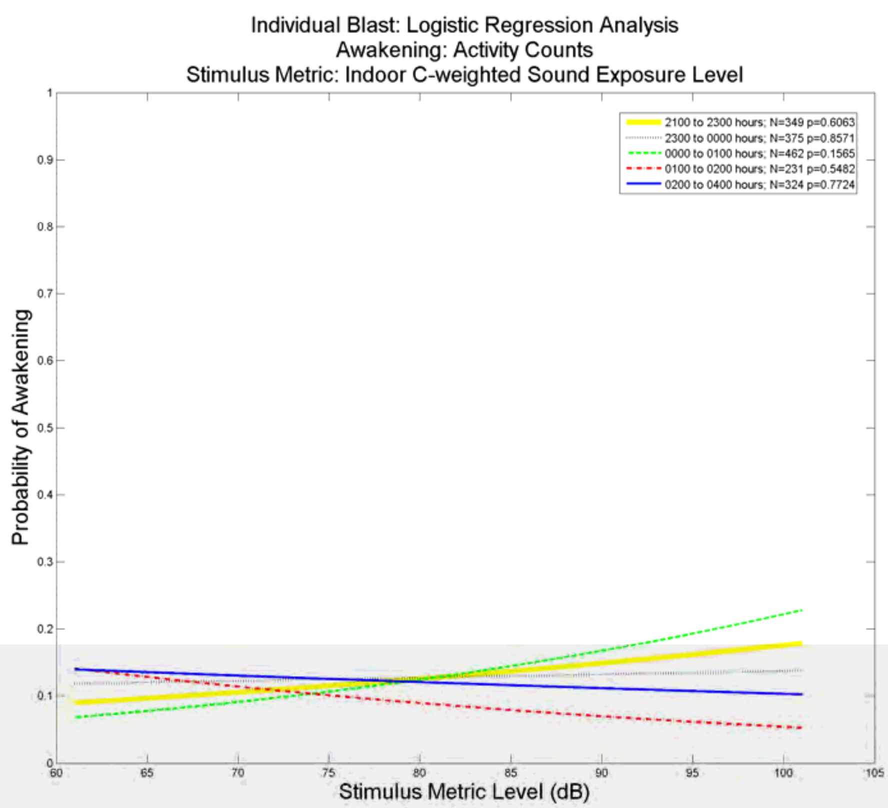
Appendix I: Activity Counts - Plots and Table



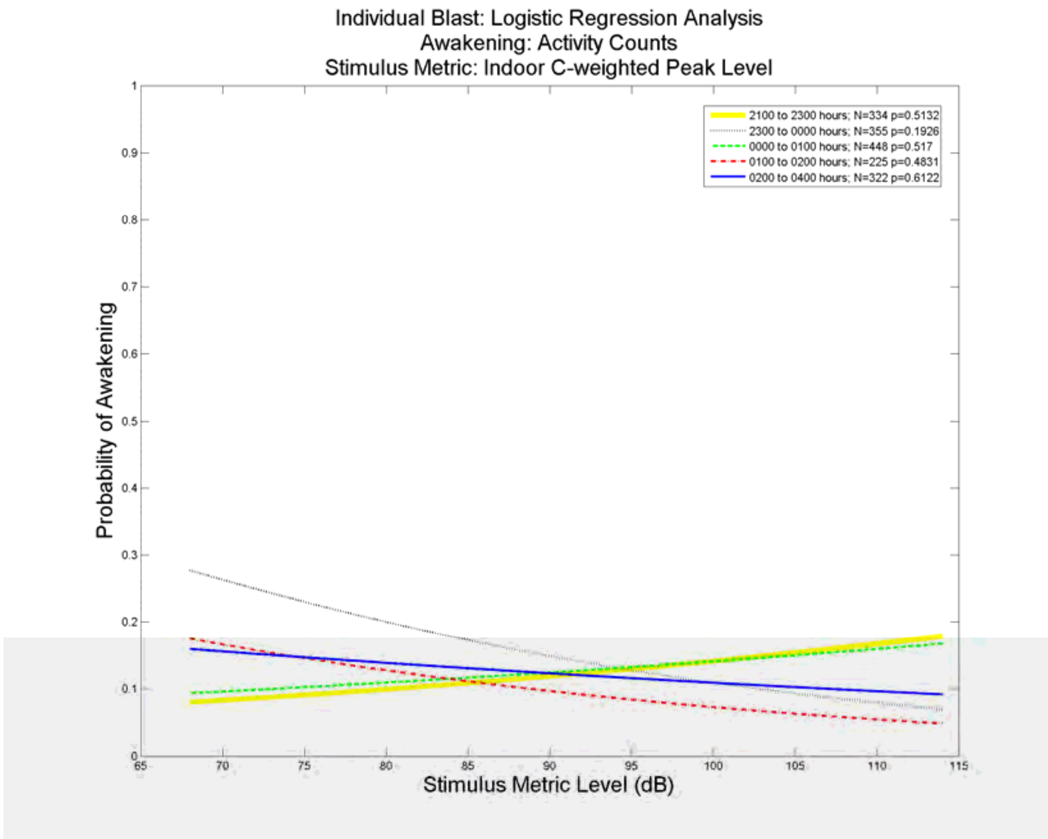


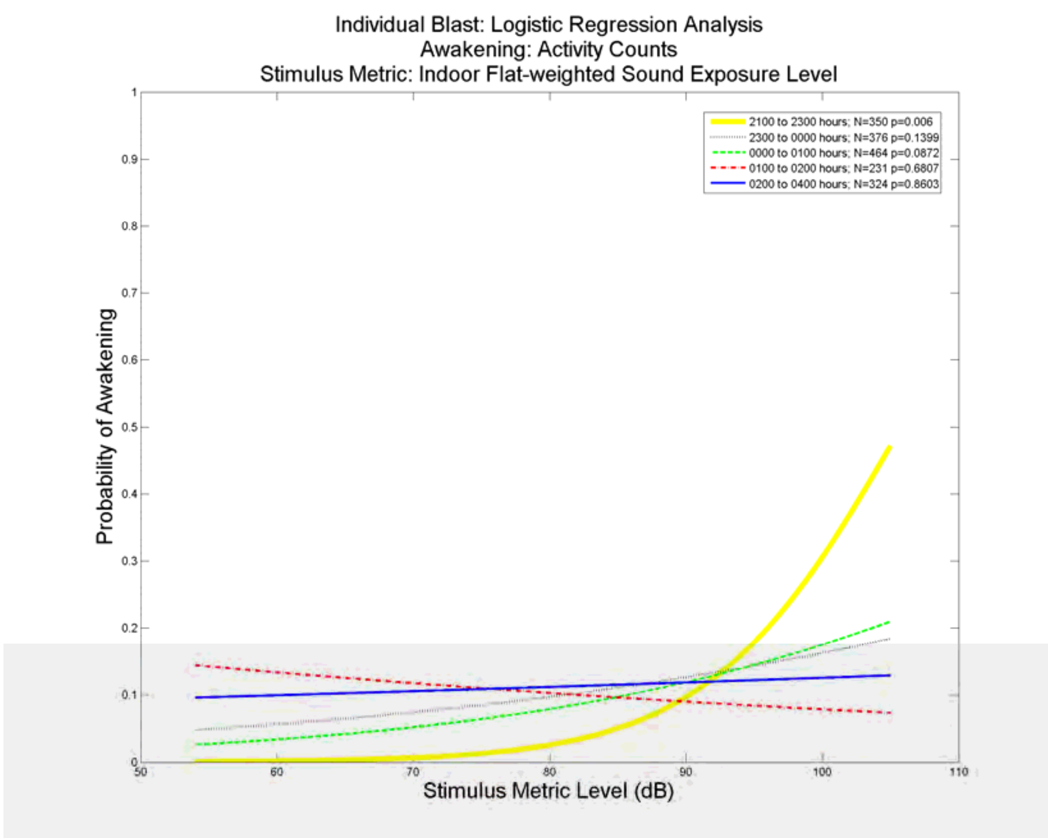


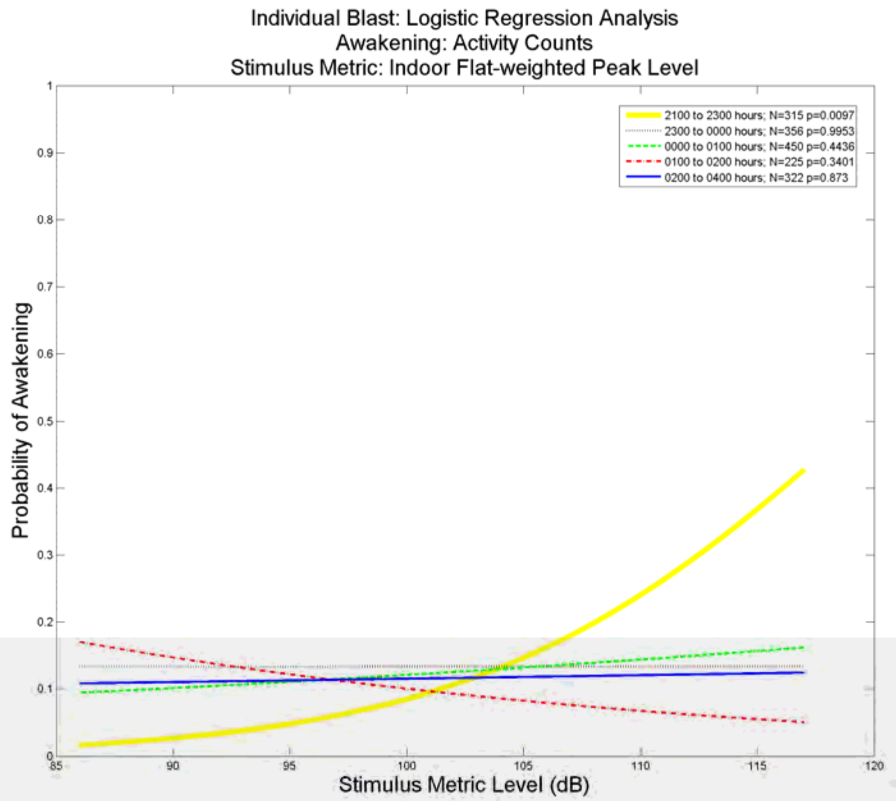
Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Indoor A-weighted Peak Level
2100 to 2300 hours; N=302 p=0.3009
2300 to 0000 hours; N=345 p=0.0293
0000 to 0100 hours; N=426 p=0.7162
0100 to 0200 hours; N=215 p=0.8547
0200 to 0400 hours; N=318 p=0.07
Probability of Awakening
Stimulus Metric Level (dB)

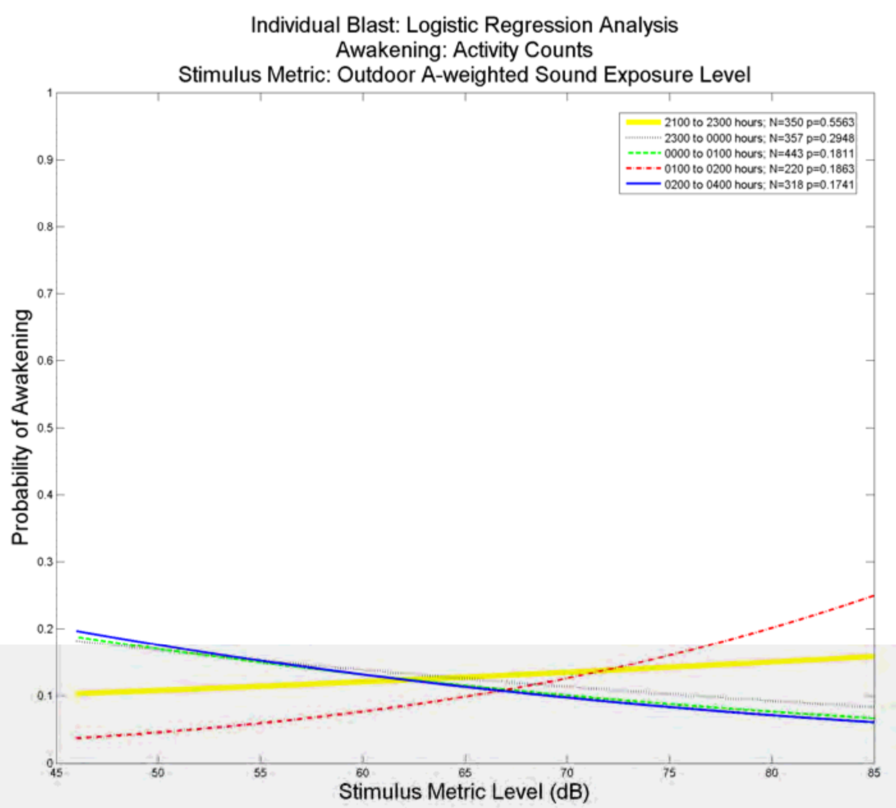


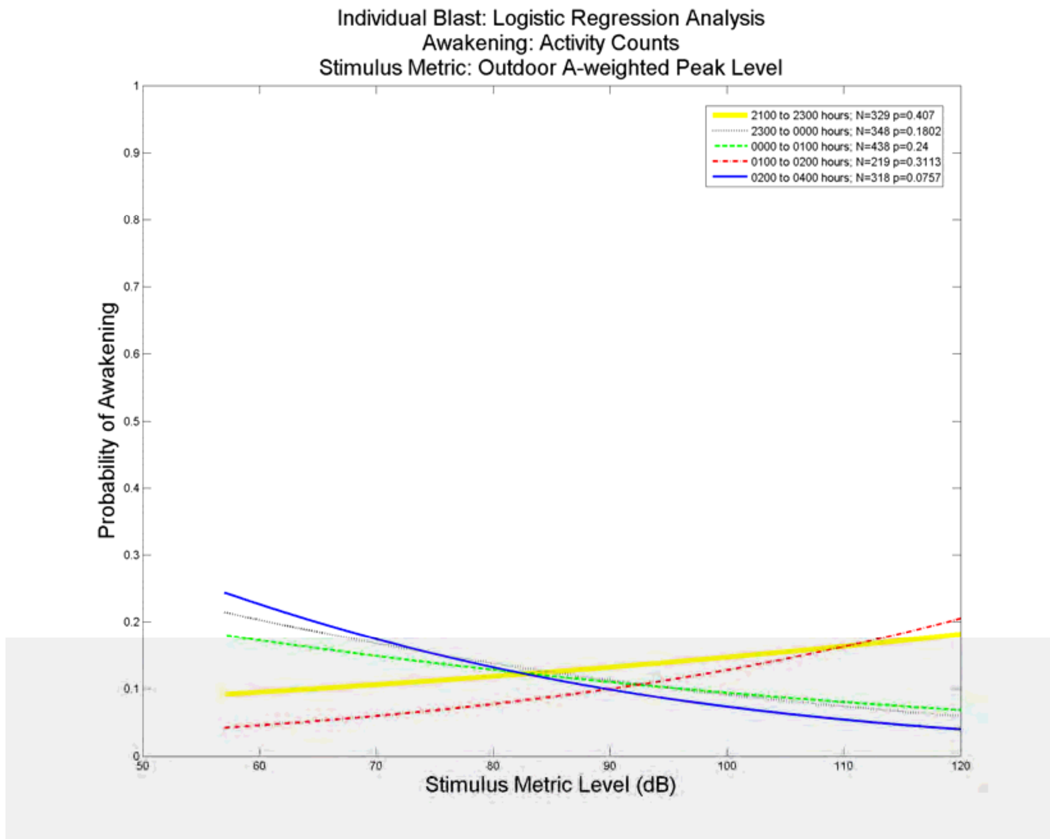
Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Indoor C-weighted Sound Exposure Level
2100 to 2300 hours; N=349 p=0.6063
2300 to 0000 hours; N=375 p=0.8571
0000 to 0100 hours; N=462 p=0.1565
0100 to 0200 hours; N=231 p=0.5482
0200 to 0400 hours; N=324 p=0.7724
Probability of Awakening
Stimulus Metric Level (dB)

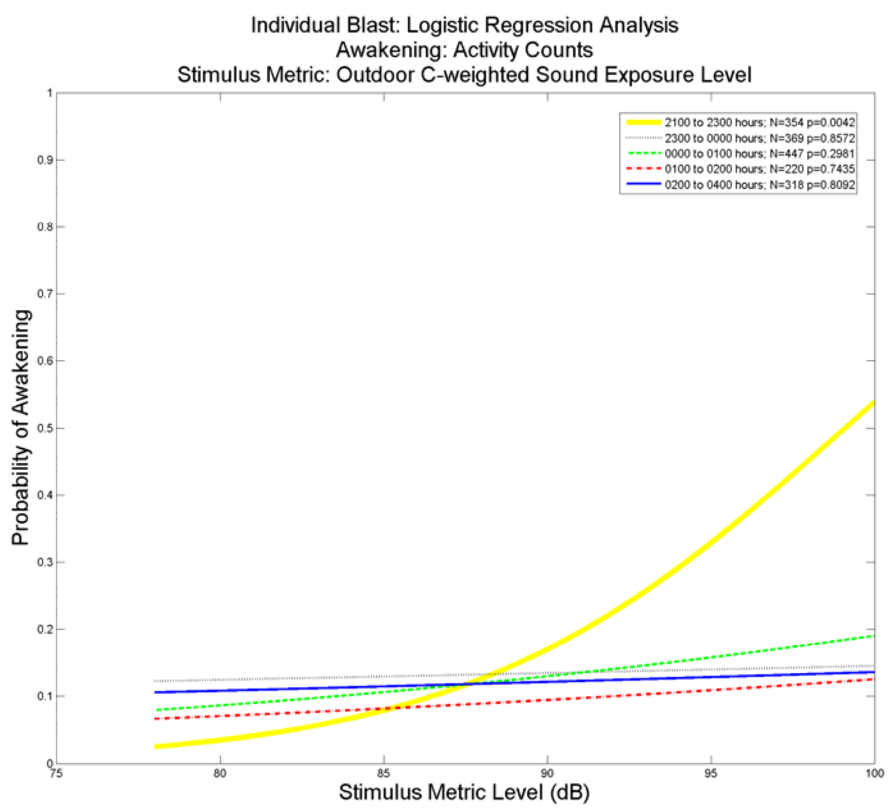

Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Indoor C-weighted Peak Level
2100 to 2300 hours; N=334 p=0.5132
2300 to 0000 hours; N=355 p=0.1926
0000 to 0100 hours; N=448 p=0.517
0100 to 0200 hours; N=225 p=0.4831
0200 to 0400 hours; N=322 p=0.6122
Probability of Awakening
Stimulus Metric Level (dB)

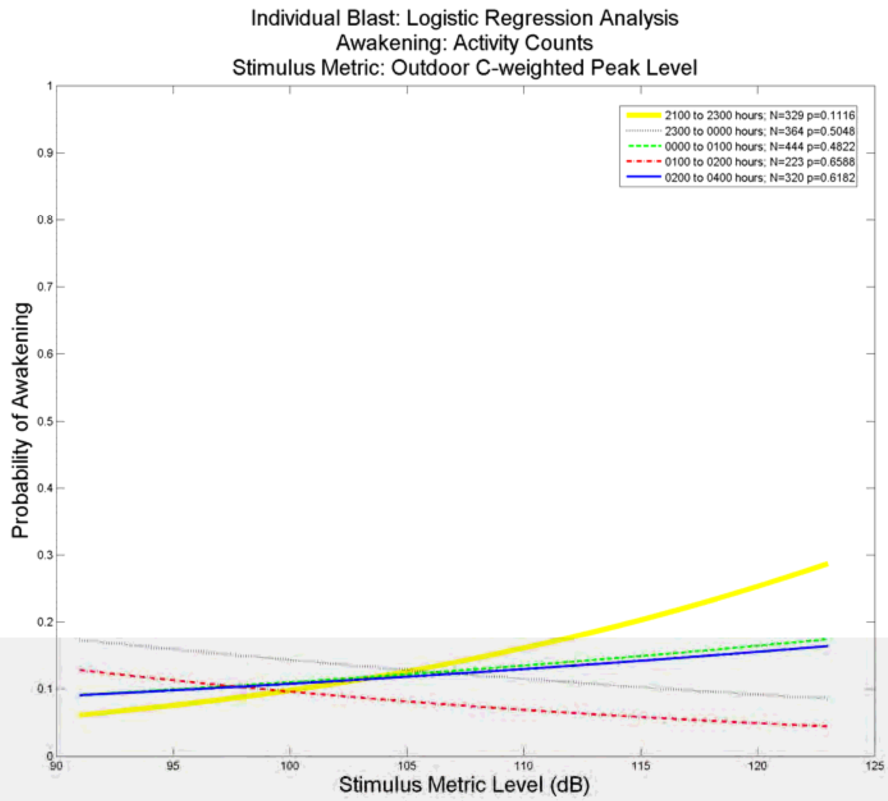

Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Indoor Flat-weighted Sound Exposure Level
2100 to 2300 hours; N=350 p=0.006
2300 to 0000 hours; N=376 p=0.1399
0000 to 0100 hours; N=464 p=0.0872
0100 to 0200 hours; N=231 p=0.6807
0200 to 0400 hours; N=324 p=0.8603
Probability of Awakening
Stimulus Metric Level (dB)

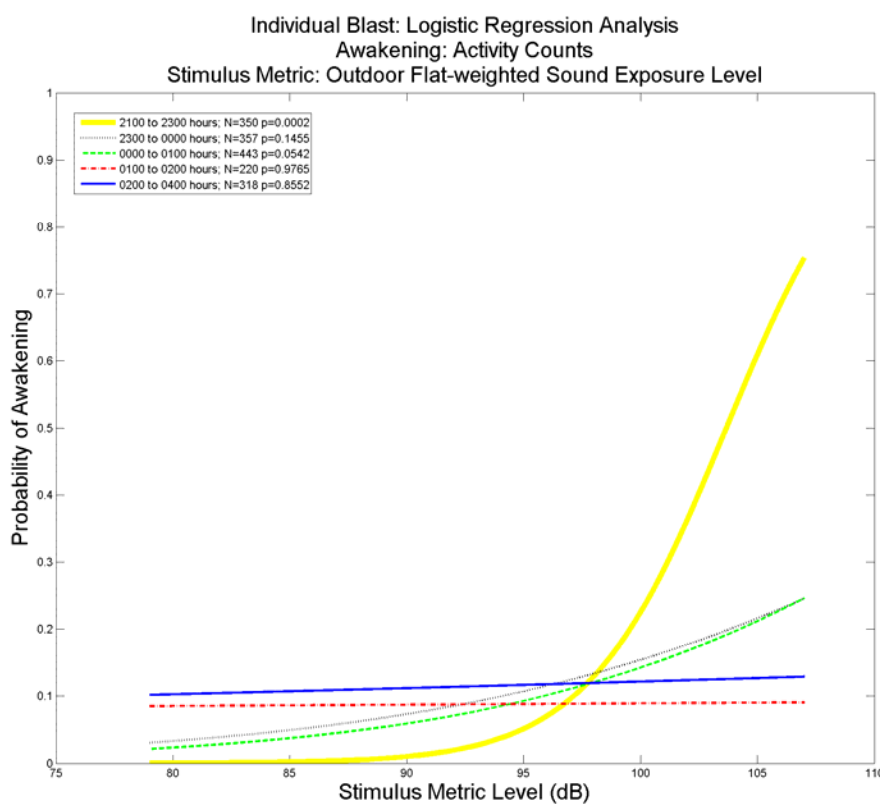

Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Indoor Flat-weighted Peak Level
2100 to 2300 hours; N=315 p=0.0097
2300 to 0000 hours; N=356 p=0.9953
0000 to 0100 hours; N=450 p=0.4436
0100 to 0200 hours; N=225 p=0.3401
0200 to 0400 hours; N=322 p=0.873
Probability of Awakening
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
85
90
95
100
105
110
115
120
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Outdoor A-weighted Sound Exposure Level
2100 to 2300 hours; N=350 p=0.5563
2300 to 0000 hours; N=357 p=0.2948
0000 to 0100 hours; N=443 p=0.1811
0100 to 0200 hours; N=220 p=0.1863
0200 to 0400 hours; N=318 p=0.1741
Probability of Awakening
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
45
50
55
60
65
70
75
80
85
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Outdoor A-weighted Peak Level
2100 to 2300 hours; N=329 p=0.407
2300 to 0000 hours; N=348 p=0.1802
0000 to 0100 hours; N=438 p=0.24
0100 to 0200 hours; N=219 p=0.3113
0200 to 0400 hours; N=318 p=0.0757
Probability of Awakening
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Outdoor C-weighted Sound Exposure Level
2100 to 2300 hours; N=354 p=0.0042
2300 to 0000 hours; N=369 p=0.8572
0000 to 0100 hours; N=447 p=0.2981
0100 to 0200 hours; N=220 p=0.7435
0200 to 0400 hours; N=318 p=0.8092
Probability of Awakening
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Outdoor C-weighted Peak Level
2100 to 2300 hours; N=329 p=0.1116
2300 to 0000 hours; N=364 p=0.5048
0000 to 0100 hours; N=444 p=0.4822
0100 to 0200 hours; N=223 p=0.6588
0200 to 0400 hours; N=320 p=0.6182
Probability of Awakening
Stimulus Metric Level (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
90
95
100
105
110
115
120
125


Individual Blast: Logistic Regression Analysis
Awakening: Activity Counts
Stimulus Metric: Outdoor Flat-weighted Sound Exposure Level
2100 to 2300 hours; N=350 p=0.0002
2300 to 0000 hours; N=357 p=0.1455
0000 to 0100 hours; N=443 p=0.0542
0100 to 0200 hours; N=220 p=0.9765
0200 to 0400 hours; N=318 p=0.8552
Probability of Awakening
Stimulus Metric Level (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
75
80
85
90
95
100
105
110

Activity Button Table

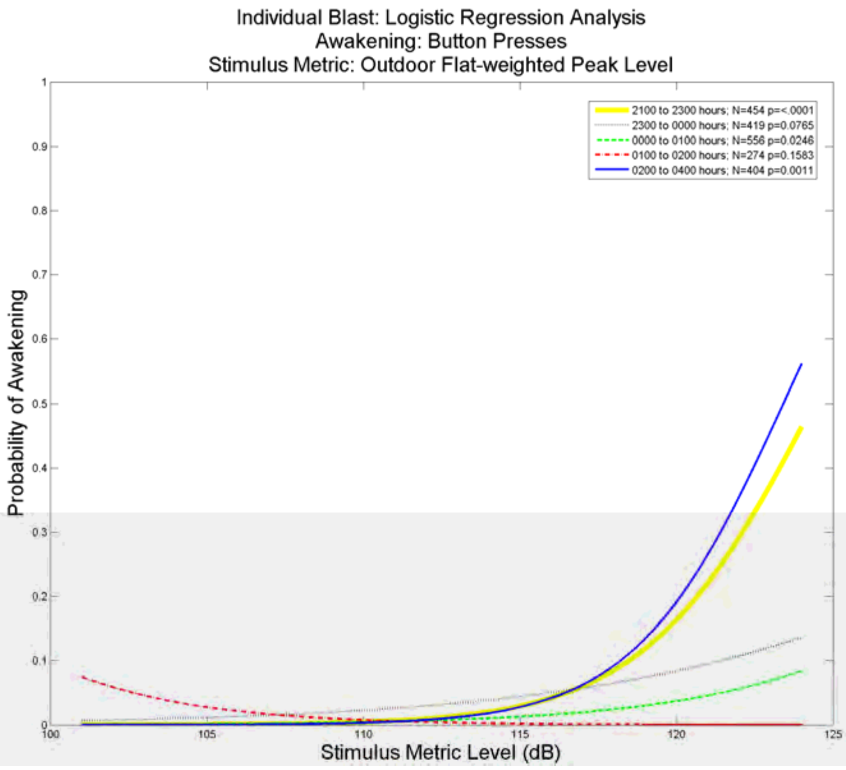
Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
2100 - 2300	329	8.8492759	1	-2.057	1.3851	0.1375	1	-0.1063	0.0707	0.1327	OAP	1	0.0124	0.0149	0.407
	333	8.8788516	1	-7.2191	3.9175	0.0654	1	-0.0792	0.0717	0.2692	OCP	1	0.057	0.0358	0.1116
	329	8.8492759	1	-25.7569	6.4868	<.0001	1	0.00399	0.0759	0.9581	OZP	1	0.2108	0.055	0.0001
	350	8.8653612	1	-1.7485	1.4322	0.2221	1	-0.1125	0.0703	0.1095	OAE	1	0.0127	0.0216	0.5563
	354	8.8930006	1	-16.9306	5.5946	0.0025	1	-0.0364	0.0733	0.6196	OCE	1	0.1741	0.0608	0.0042
	350	8.8653612	1	-35.1855	9.3285	0.0002	1	0.0373	0.0897	0.6774	OZE	1	0.3362	0.0914	0.0002
	302	8.8439193	1	-2.5849	1.6261	0.1119	1	-0.118	0.0819	0.1498	IAP	1	0.0248	0.024	0.3009
	334	9.0096827	1	-2.9292	3.0158	0.3314	1	-0.0962	0.0719	0.1808	ICP	1	0.0199	0.0304	0.5132
	315	9.21391	1	-14.1036	5.2154	0.0068	1	-0.0568	0.0808	0.4822	IZP	1	0.1225	0.0474	0.0097
	317	8.7000398	1	-1.2174	1.1264	0.2798	1	-0.0945	0.0806	0.2406	IAE	1	0.002	0.0214	0.9256
	349	8.871871	1	-2.7196	3.262	0.4044	1	-0.0901	0.0687	0.1895	ICE	1	0.0197	0.0382	0.6063
	350	8.8728456	1	-15.286	5.2402	0.0035	1	0.0378	0.0841	0.6533	IZE	1	0.1413	0.0514	0.006
2300 - 0000	348	8.4418913	1	0.781	1.459	0.5925	1	-0.0896	0.0645	0.1651	OAP	1	-0.0232	0.0173	0.1802
	364	8.5680257	1	1.66	4.0329	0.6806	1	-0.1087	0.0619	0.0792	OCP	1	-0.0252	0.0378	0.5048
	348	8.4418913	1	-5.8294	5.6878	0.3054	1	-0.084	0.0682	0.2181	OZP	1	0.0412	0.0488	0.399
	357	8.446794	1	0.2796	1.368	0.8381	1	-0.0866	0.0632	0.1709	OAE	1	-0.0229	0.0218	0.2948
	369	8.5399535	1	-1.8412	4.4976	0.6823	1	-0.0965	0.062	0.1198	OCE	1	0.00893	0.0496	0.8572
	357	8.446794	1	-9.4294	5.7831	0.103	1	-0.0729	0.0645	0.2585	OZE	1	0.0834	0.0573	0.1455
	345	8.7374414	1	2.6012	1.5974	0.1034	1	-0.0878	0.0674	0.1932	IAP	1	-0.0556	0.0255	0.0293
	355	8.7468865	1	2.5709	2.5837	0.3197	1	-0.1267	0.067	0.0587	ICP	1	-0.0356	0.0274	0.1926

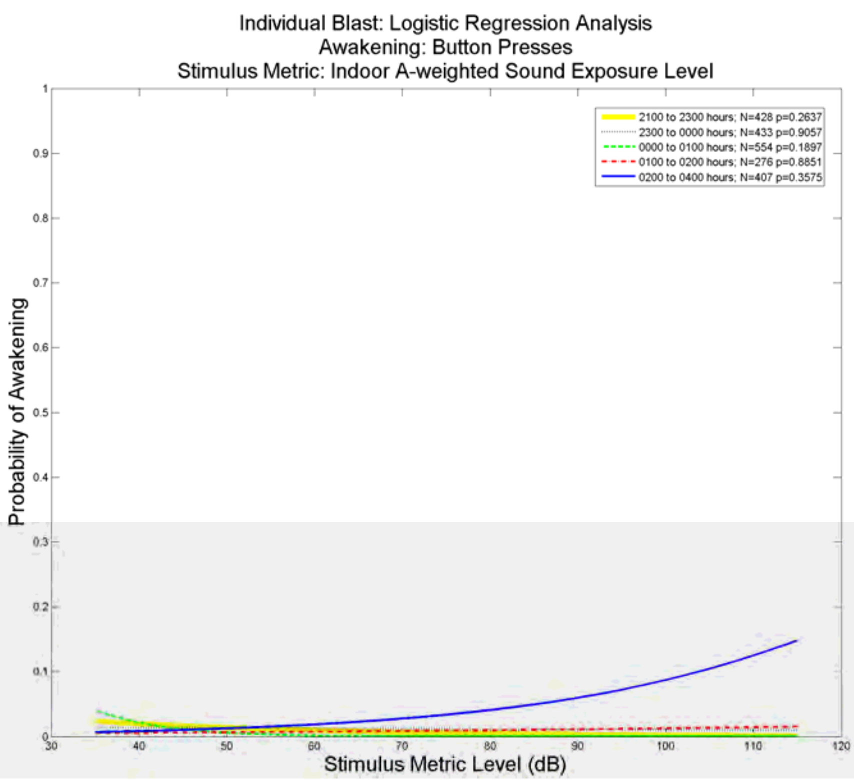
Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
	356	8.7481957	1	-0.7653	3.4016	0.822	1	-0.129	0.069	0.0616	IZP	1	0.000183	0.0309	0.9953
	365	8.5766647	1	1.1092	1.0075	0.2709	1	-0.0638	0.0656	0.3302	IAE	1	-0.0438	0.019	0.0213
	375	8.5898934	1	-1.2969	1.8754	0.4892	1	-0.1131	0.0634	0.0743	ICE	1	0.00428	0.0238	0.8571
	376	8.5915505	1	-3.6365	1.9265	0.0591	1	-0.1108	0.0619	0.0735	IZE	1	0.0295	0.02	0.1399
0000-0100	438	8.4511685	1	-1.2242	1.2739	0.3366	1	0.0829	0.0502	0.0988	OAP	1	-0.0174	0.0148	0.24
	444	8.489821	1	-5.0803	3.5118	0.148	1	0.0787	0.0502	0.1172	OCP	1	0.0232	0.0329	0.4822
	438	8.4511685	1	-7.935	4.3951	0.071	1	0.089	0.051	0.0809	OZP	1	0.0461	0.0379	0.2237
	443	8.4532588	1	-0.7965	1.4275	0.5769	1	0.0854	0.0508	0.0924	OAE	1	-0.0302	0.0226	0.1811
	447	8.4788354	1	-6.7105	3.9527	0.0896	1	0.083	0.0508	0.1024	OCE	1	0.0456	0.0439	0.2981
	443	8.4532588	1	-12.2461	5.0449	0.0152	1	0.0911	0.053	0.0853	OZE	1	0.0968	0.0503	0.0542
	426	8.6320534	1	-3.1385	1.5435	0.042	1	0.0732	0.0563	0.1939	IAP	1	0.00864	0.0238	0.7162
	448	8.6666572	1	-3.8745	2.1189	0.0675	1	0.0712	0.0509	0.1623	ICP	1	0.0145	0.0224	0.517
	450	8.6690852	1	-4.66	2.814	0.0977	1	0.079	0.0515	0.1254	IZP	1	0.0199	0.026	0.4436
	440	8.5420466	1	-2.8262	0.9988	0.0047	1	0.0895	0.0519	0.0843	IAE	1	0.00163	0.0175	0.9257
	462	8.5798877	1	-5.3692	1.9858	0.0069	1	0.0727	0.0499	0.1447	ICE	1	0.0349	0.0247	0.1565
	464	8.5826165	1	-6.7938	2.504	0.0067	1	0.0852	0.0491	0.0829	IZE	1	0.0451	0.0264	0.0872
0100 - 0200	219	8.4335243	1	-5.4945	2.4345	0.024	1	0.0922	0.0653	0.1581	OAP	1	0.028	0.0277	0.3113
	223	8.4851463	1	0.6828	8.6937	0.9374	1	0.0817	0.0666	0.2202	OCP	1	-0.0362	0.082	0.6588
	219	8.4335243	1	-1.2973	9.2474	0.8884	1	0.0851	0.0729	0.2435	OZP	1	-0.0162	0.0801	0.8401

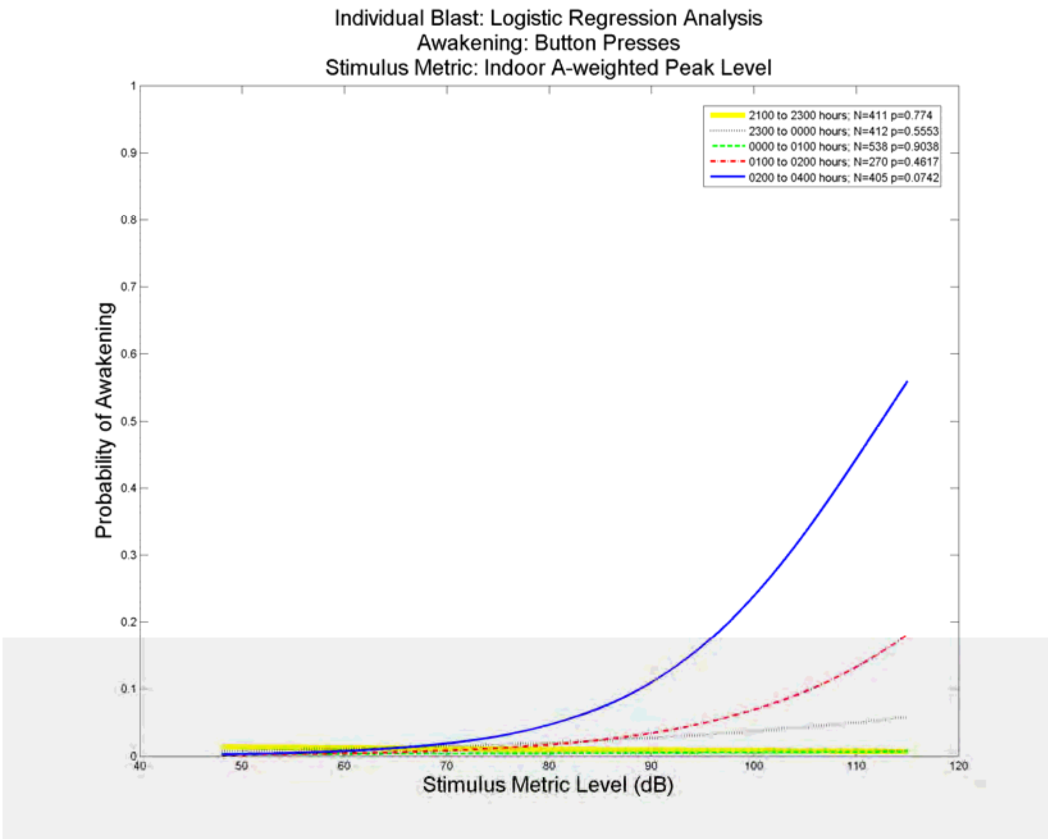
Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
	220	8.4202881	1	-6.4871	2.7909	0.0201	1	0.0803	0.0692	0.2462	OAE	1	0.0554	0.0419	0.1863
	220	8.4202881	1	-5.8476	8.7965	0.5062	1	0.0861	0.071	0.2254	OCE	1	0.0318	0.0971	0.7435
	220	8.4202881	1	-3.2308	8.5103	0.7042	1	0.0783	0.0717	0.2746	OZE	1	0.00249	0.0844	0.9765
	215	8.6613156	1	-3.5835	2.6823	0.1816	1	0.0801	0.0797	0.3151	IAP	1	0.00783	0.0428	0.8547
	225	8.632673	1	-0.244	4.0833	0.9523	1	0.0938	0.067	0.1617	ICP	1	-0.0311	0.0444	0.4831
	225	8.632673	1	1.3734	4.6772	0.769	1	0.0906	0.0688	0.1881	IZP	1	-0.0435	0.0456	0.3401
	221	8.5824468	1	-2.3781	1.5347	0.1212	1	0.0891	0.0714	0.2121	IAE	1	-0.0131	0.0299	0.6618
	231	8.5579624	1	-0.939	3.4201	0.7837	1	0.0907	0.069	0.1886	ICE	1	-0.027	0.045	0.5482
	231	8.5579624	1	-6.7938	2.504	0.0067	1	0.0852	0.0491	0.0829	IZE	1	0.0451	0.0264	0.0872
0200 - 0400	318	8.4729405	1	0.26	1.4958	0.862	1	0.055	0.0595	0.3554	OAP	1	-0.0326	0.0184	0.0757
	320	8.4906812	1	-4.5156	4.529	0.3187	1	0.034	0.0608	0.5761	OCP	1	0.0211	0.0423	0.6182
	318	8.4729405	1	-5.7635	5.3755	0.2836	1	0.0442	0.0625	0.4791	OZP	1	0.0301	0.0463	0.5156
	318	8.4729405	1	-0.2192	1.5876	0.8902	1	0.0455	0.058	0.4325	OAE	1	-0.0342	0.0251	0.1741
	318	8.4729405	1	-3.4703	4.9153	0.4802	1	0.0379	0.0624	0.5439	OCE	1	0.013	0.054	0.8092
	318	8.4729405	1	-3.2511	5.2925	0.539	1	0.0378	0.0639	0.554	OZE	1	0.00954	0.0523	0.8552
	318	8.5490246	1	0.6454	1.7348	0.7099	1	0.0607	0.0568	0.285	IAP	1	-0.0478	0.0264	0.07
	322	8.5424138	1	-1.102	2.6022	0.6719	1	0.0435	0.0591	0.4613	ICP	1	-0.0137	0.027	0.6122
	322	8.5424138	1	-2.9466	3.4961	0.3993	1	0.0474	0.0651	0.4665	IZP	1	0.00502	0.0314	0.873
	320	8.5318636	1	-1.2584	1.2192	0.302	1	0.0474	0.0587	0.4198	IAE	1	-0.0204	0.022	0.3539
	324	8.5255055	1	-1.5826	2.5399	0.5332	1	0.0353	0.0589	0.5494	ICE	1	-0.00883	0.0305	0.7724
	324	8.5255055	1	-2.9385	3.6596	0.422	1	0.0404	0.0635	0.5253	IZE	1	0.00653	0.0371	0.8603

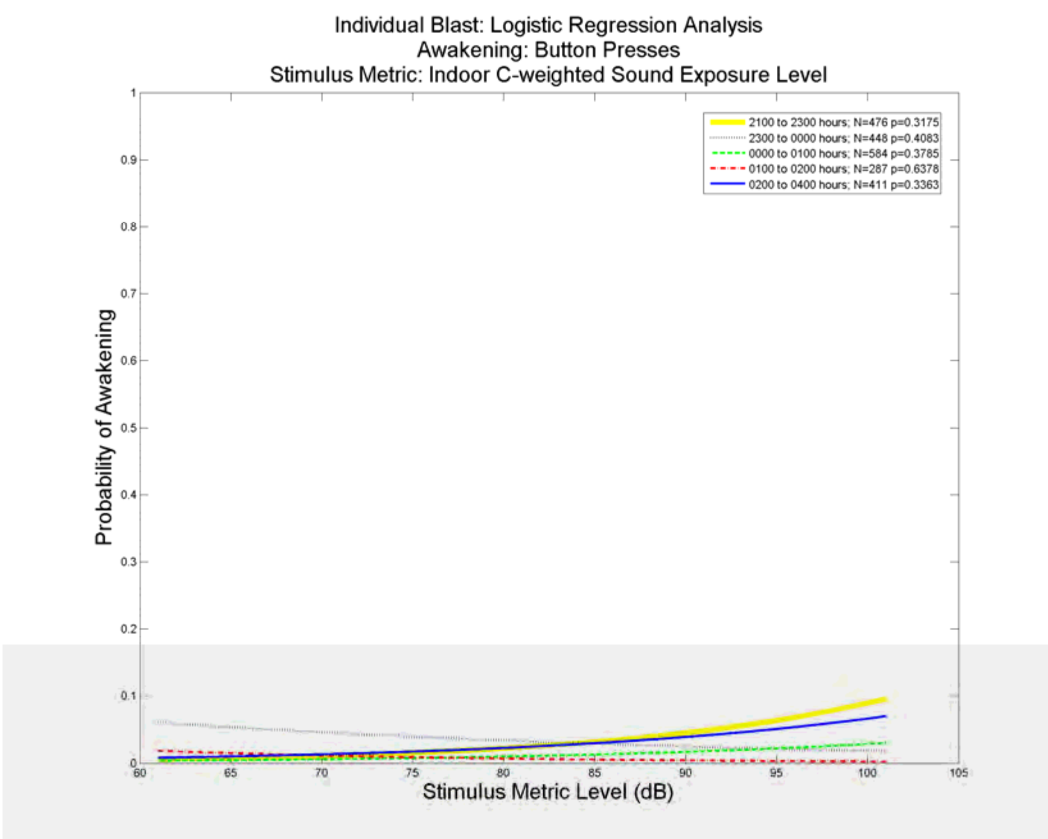
Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
KEY															
OAP = Outdoor A-Weighed Peak Level															
OCP = Outdoor C-Weighted Peak Level															
OZP = Outdoor Flat-Weighted Peak Level															
OAE = Outdoor A-Weighted Sound Exposure Level															
OCE = Outdoor C-Weighted Sound Exposure Level															
OZE = Outdoor Flat-Weighted Sound Exposure Level															
IAP = Indoor A-Weighted Peak Level															
ICP = Indoor C-Weighted Peak Level															
IZP = Indoor Flat-Weighted Peak Level															
IAE = Indoor A-Weighted Sound Exposure Level															
ICE = Indoor C-Weighted Sound Exposure Level															
IZE = Indoor Flat-Weighted Sound Exposure Level															

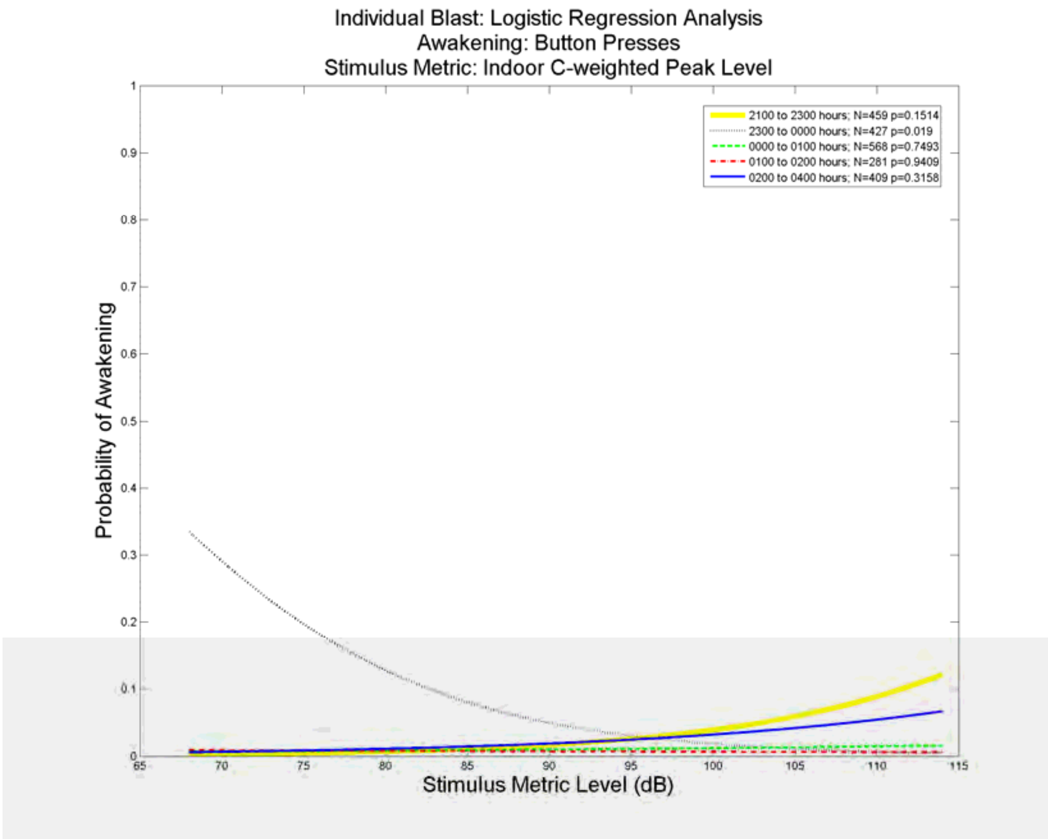
Appendix J: Button Presses - Plots and Table

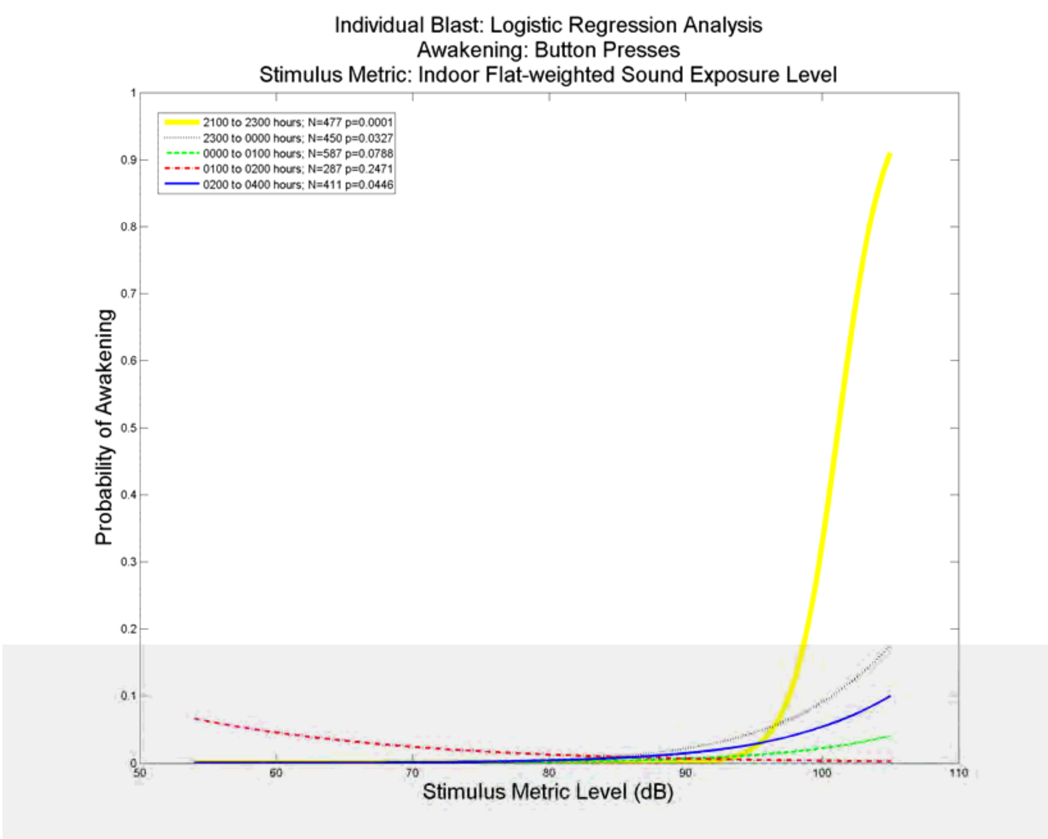


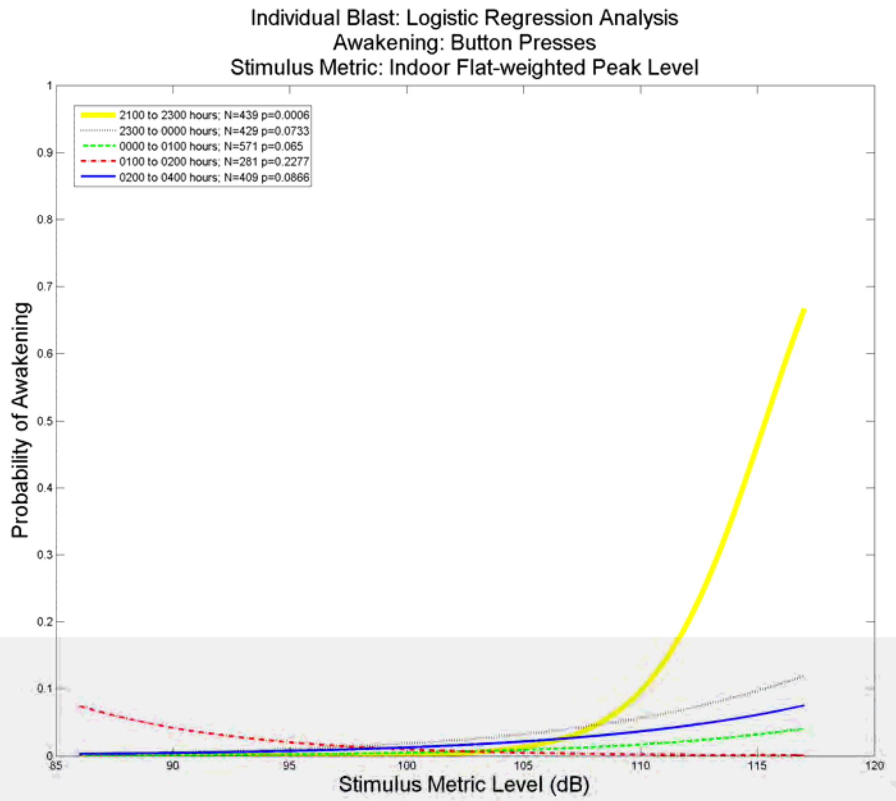


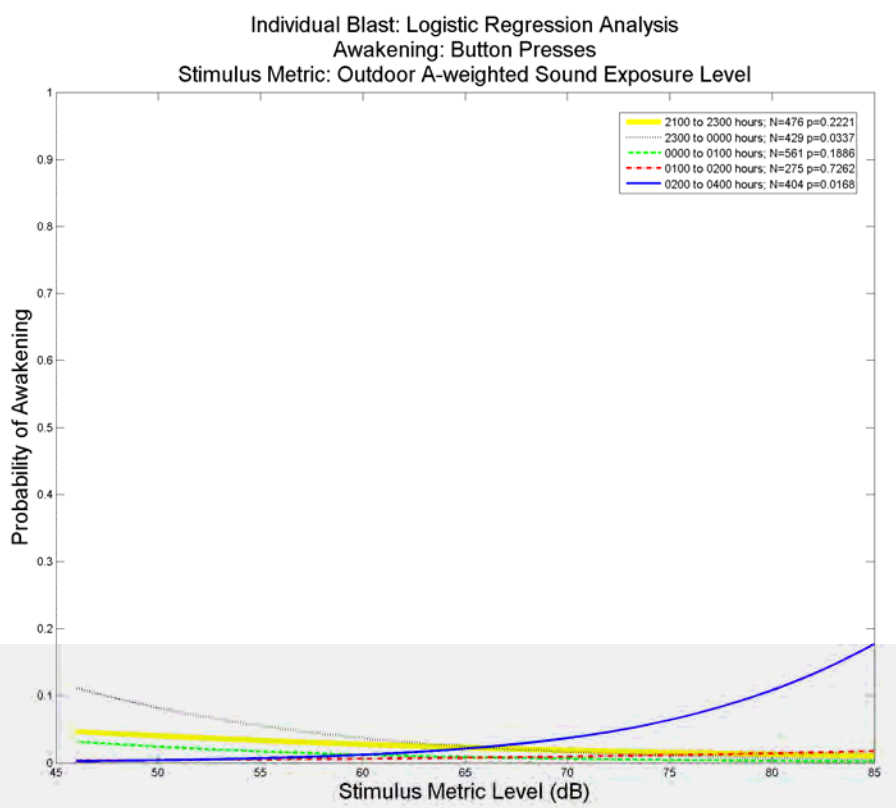

Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Indoor A-weighted Peak Level
2100 to 2300 hours; N=411 p=0.774
2300 to 0000 hours; N=412 p=0.5553
0000 to 0100 hours; N=538 p=0.9038
0100 to 0200 hours; N=270 p=0.4617
0200 to 0400 hours; N=405 p=0.0742
Probability of Awakening
Stimulus Metric Level (dB)

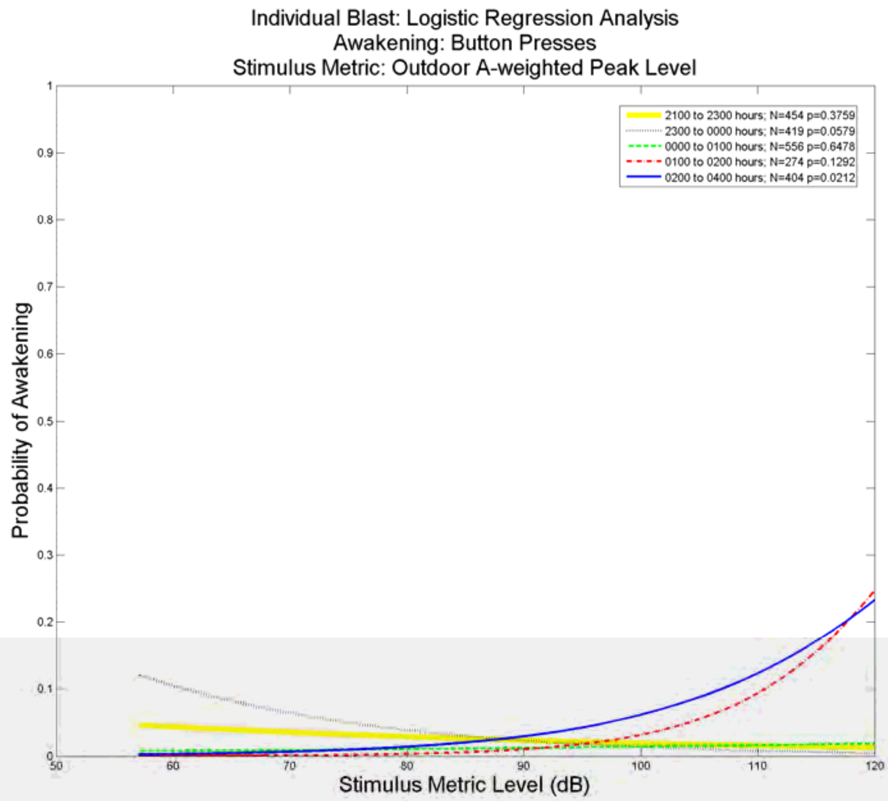

Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Indoor C-weighted Sound Exposure Level
2100 to 2300 hours; N=476 p=0.3175
2300 to 0000 hours; N=448 p=0.4083
0000 to 0100 hours; N=584 p=0.3785
0100 to 0200 hours; N=287 p=0.6378
0200 to 0400 hours; N=411 p=0.3363
Probability of Awakening
Stimulus Metric Level (dB)

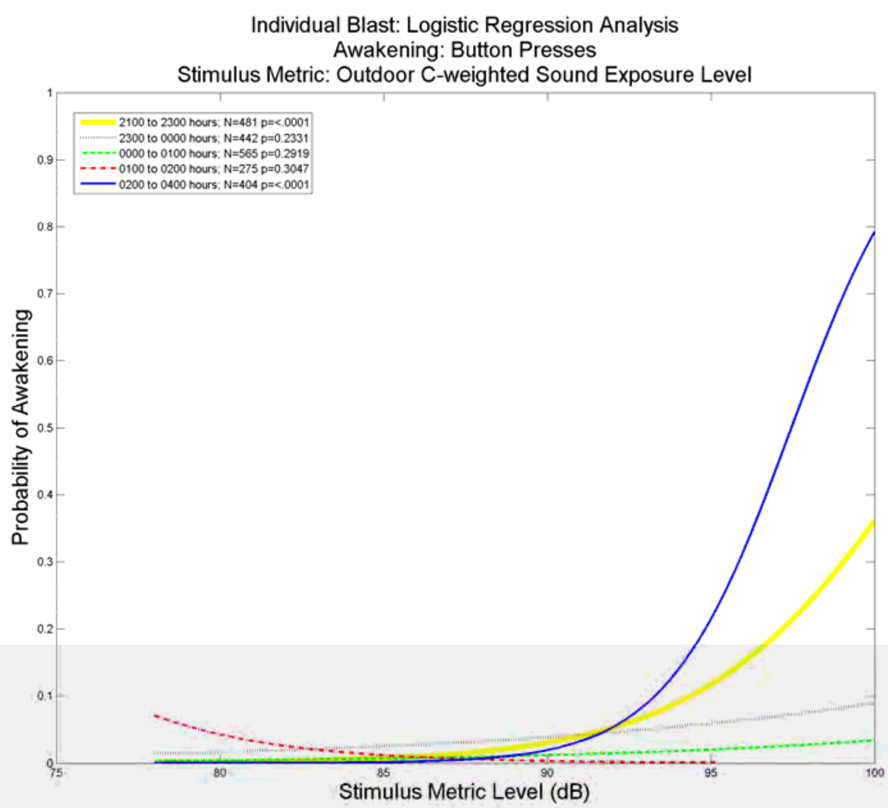

Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Indoor C-weighted Peak Level
2100 to 2300 hours; N=459 p=0.1514
2300 to 0000 hours; N=427 p=0.019
0000 to 0100 hours; N=568 p=0.7493
0100 to 0200 hours; N=281 p=0.9409
0200 to 0400 hours; N=409 p=0.3158
Probability of Awakening
Stimulus Metric Level (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
65
70
75
80
85
90
95
100
105
110
115

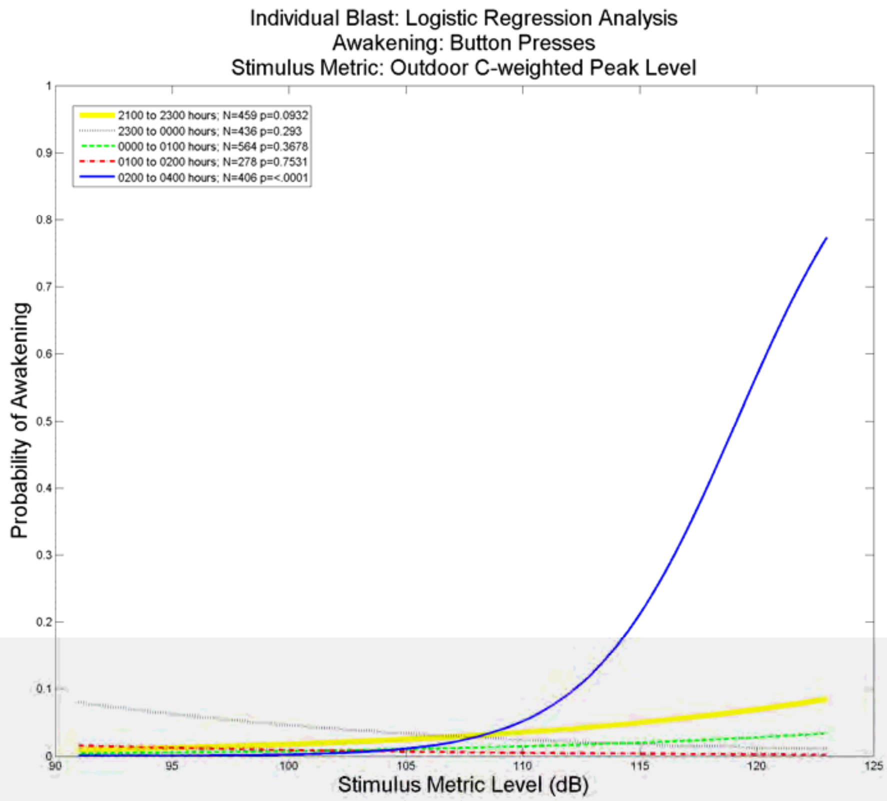

Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Indoor Flat-weighted Sound Exposure Level
2100 to 2300 hours; N=477 p=0.0001
2300 to 0000 hours; N=450 p=0.0327
0000 to 0100 hours; N=587 p=0.0788
0100 to 0200 hours; N=287 p=0.2471
0200 to 0400 hours; N=411 p=0.0446
Probability of Awakening
Stimulus Metric Level (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
50
60
70
80
90
100
110

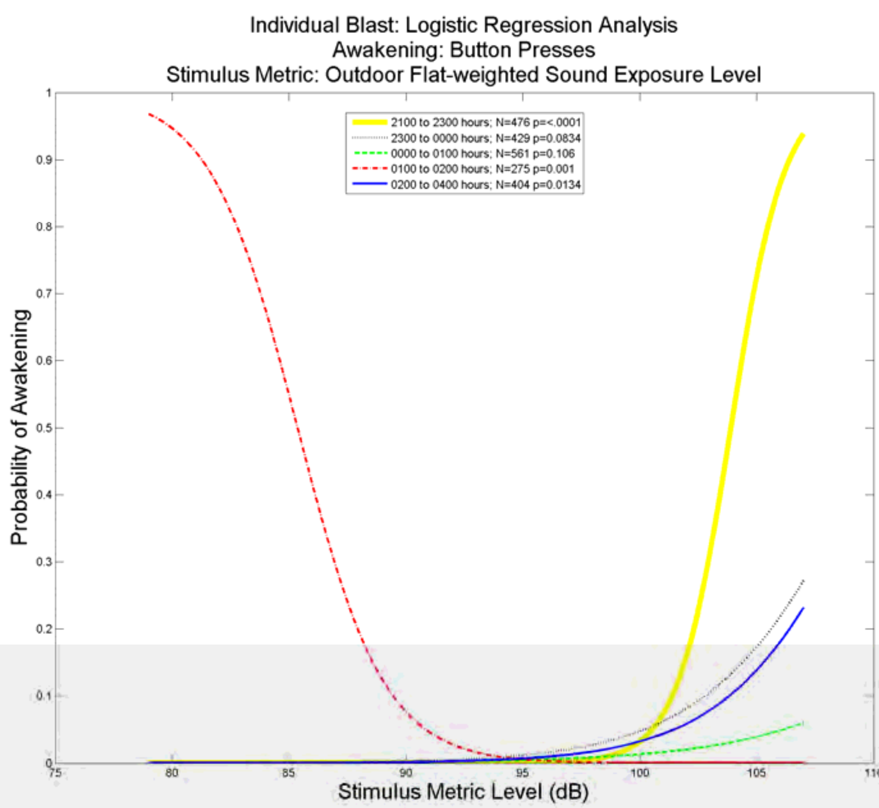

Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Indoor Flat-weighted Peak Level
2100 to 2300 hours; N=439 p=0.0006
2300 to 0000 hours; N=429 p=0.0733
0000 to 0100 hours; N=571 p=0.065
0100 to 0200 hours; N=281 p=0.2277
0200 to 0400 hours; N=409 p=0.0866
Probability of Awakening
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Outdoor A-weighted Sound Exposure Level
2100 to 2300 hours; N=476 p=0.2221
2300 to 0000 hours; N=429 p=0.0337
0000 to 0100 hours; N=561 p=0.1886
0100 to 0200 hours; N=275 p=0.7262
0200 to 0400 hours; N=404 p=0.0168
Probability of Awakening
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Outdoor A-weighted Peak Level
2100 to 2300 hours; N=454 p=0.3759
2300 to 0000 hours; N=419 p=0.0579
0000 to 0100 hours; N=556 p=0.6478
0100 to 0200 hours; N=274 p=0.1292
0200 to 0400 hours; N=404 p=0.0212
Probability of Awakening
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Outdoor C-weighted Sound Exposure Level
2100 to 2300 hours; N=481 p=<.0001
2300 to 0000 hours; N=442 p=0.2331
0000 to 0100 hours; N=565 p=0.2919
0100 to 0200 hours; N=275 p=0.3047
0200 to 0400 hours; N=404 p=<.0001
Probability of Awakening
Stimulus Metric Level (dB)


Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Outdoor C-weighted Peak Level
2100 to 2300 hours; N=459 p=0.0932
2300 to 0000 hours; N=436 p=0.293
0000 to 0100 hours; N=564 p=0.3678
0100 to 0200 hours; N=278 p=0.7531
0200 to 0400 hours; N=406 p=<.0001
Probability of Awakening
Stimulus Metric Level (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
90
95
100
105
110
115
120
125


Individual Blast: Logistic Regression Analysis
Awakening: Button Presses
Stimulus Metric: Outdoor Flat-weighted Sound Exposure Level
2100 to 2300 hours; N=476 p=<.0001
2300 to 0000 hours; N=429 p=0.0834
0000 to 0100 hours; N=561 p=0.106
0100 to 0200 hours; N=275 p=0.001
0200 to 0400 hours; N=404 p=0.0134
Probability of Awakening
Stimulus Metric Level (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
75
80
85
90
95
100
105
110

Button Presses Table

Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
2100 - 2300	454	0.2750511	1	-3.8852	2.1596	0.072	1	7.5073	1.9388	0.0001	OAP	1	-0.0212	0.024	0.3759
	459	0.2738736	1	-13.5369	4.7685	0.0045	1	8.6587	1.8101	<.0001	OCP	1	0.0714	0.0425	0.0932
	454	0.2750511	1	-50.029	10.0399	<.0001	1	13.5708	2.7506	<.0001	OZP	1	0.3722	0.0814	<.0001
	476	0.2765349	1	-3.3216	2.0763	0.1096	1	7.6769	1.8283	<.0001	OAE	1	-0.0395	0.0324	0.2221
	481	0.2753958	1	-32.272	6.7393	<.0001	1	9.8043	1.8088	<.0001	OCE	1	0.29	0.0717	<.0001
	476	0.2765349	1	-94.9809	14.1343	<.0001	1	14.2053	2.216	<.0001	OZE	1	0.8764	0.1361	<.0001
	411	0.2516099	1	-8.2072	3.1535	0.0093	1	17.5913	3.8306	<.0001	IAP	1	-0.0103	0.036	0.774
	459	0.2747249	1	-15.1712	6.6637	0.0228	1	11.5762	3.4147	0.0007	ICP	1	0.0878	0.0612	0.1514
	439	0.2779052	1	-53.6489	14.4863	0.0002	1	19.2729	5.2838	0.0003	IZP	1	0.4187	0.1219	0.0006
	428	0.2506286	1	-6.5017	2.6395	0.0138	1	16.4074	3.6732	<.0001	IAE	1	-0.0377	0.0337	0.2637
	476	0.2730171	1	-12.5425	6.6585	0.0596	1	10.4722	2.8496	0.0002	ICE	1	0.0736	0.0736	0.3175
	477	0.2738423	1	-67.7698	16.6065	<.0001	1	22.8848	5.5601	<.0001	IZE	1	0.6078	0.1578	0.0001
2300 - 0000	419	0.2812291	1	0.2133	2.3501	0.9277	1	3.0796	0.9662	0.0014	OAP	1	-0.0537	0.0283	0.0579
	436	0.2767735	1	2.5446	6.5427	0.6973	1	3.6169	0.8966	<.0001	OCP	1	-0.0658	0.0626	0.293
	419	0.2812291	1	-20.0289	8.9718	0.0256	1	4.6811	1.2488	0.0002	OZP	1	0.136	0.0768	0.0765
	429	0.280781	1	0.8801	2.4137	0.7154	1	3.3929	0.9855	0.0006	OAE	1	-0.085	0.04	0.0337
	442	0.2774332	1	-12.4044	6.7791	0.0673	1	4.2096	1.0135	<.0001	OCE	1	0.0891	0.0747	0.2331
	249	0.280781	1	-33.2076	16.8778	0.0491	1	5.1536	1.7933	0.0041	OZE	1	0.2876	0.1662	0.0834
	412	0.2609188	1	-10.7562	4.6287	0.0201	1	16.652	4.5412	0.0002	IAP	1	0.0315	0.0533	0.5553

Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
	427	0.2760253	1	5.7469	4.2412	0.1754	1	2.0982	1.0571	0.0472	ICP	1	-0.1031	0.044	0.019
	429	0.2778464	1	-17.439	7.4264	0.0189	1	6.3656	1.9083	0.0009	IZP	1	0.1168	0.0652	0.0733
	433	0.2592692	1	-7.9201	3.6366	0.0294	1	15.055	4.5588	0.001	IAE	1	-0.00545	0.046	0.9057
	448	0.2737228	1	-1.7618	3.2256	0.5849	1	3.5532	1.0277	0.0005	ICE	1	-0.0321	0.0389	0.4083
	450	0.2754692	1	-19.0526	7.0041	0.0065	1	6.0064	1.5574	0.0001	IZE	1	0.1509	0.0706	0.0327
0000 - 0100	556	0.2901443	1	-7.277	2.9126	0.0125	1	5.2846	0.8632	<.0001	OAP	1	0.0149	0.0325	0.6478
	564	0.2883969	1	-13.237	8.118	0.103	1	5.5654	0.9381	<.0001	OCP	1	0.0673	0.0748	0.3678
	556	0.2901443	1	-31.0784	11.3329	0.0061	1	6.947	1.2145	<.0001	OZP	1	0.2151	0.0957	0.0246
	561	0.2898935	1	-1.6505	3.2453	0.611	1	5.0504	0.8421	<.0001	OAE	1	-0.0704	0.0536	0.1886
	565	0.2890232	1	-15.737	9.3286	0.0916	1	5.6505	0.9356	<.0001	OCE	1	0.1075	0.102	0.2919
	561	0.2898935	1	-28.3246	13.9841	0.0428	1	6.0988	1.1074	<.0001	OZE	1	0.2224	0.1376	0.106
	538	0.2592205	1	-10.2506	8.5705	0.2317	1	14.8304	8.3324	0.0751	IAP	1	0.012	0.0991	0.9038
	568	0.2840504	1	-7.9203	6.0774	0.1925	1	5.4503	1.2064	<.0001	ICP	1	0.0195	0.0611	0.7493
	571	0.2860607	1	-20.6085	8.0415	0.0104	1	7.8755	1.7271	<.0001	IZP	1	0.1299	0.0704	0.065
	554	0.2582872	1	-0.7362	6.1623	0.9049	1	8.2584	5.8191	0.1558	IAE	1	-0.1302	0.0993	0.1897
	584	0.2824848	1	-10.6967	5.389	0.0472	1	5.8917	1.1238	<.0001	ICE	1	0.055	0.0625	0.3785
	587	0.2844483	1	-18.3549	7.1562	0.0103	1	7.1454	1.4469	<.0001	IZE	1	0.1253	0.0713	0.0788
0100 - 0200	274	0.2952758	1	-14.6144	7.3104	0.0456	1	-1.1813	5.7563	0.8374	OAP	1	0.1154	0.076	0.1292
	278	0.2934294	1	2.2763	20.9524	0.9135	1	-2.262	5.8454	0.6988	OCP	1	-0.0632	0.2009	0.7531
	274	0.2952758	1	24.1511	19.8834	0.2245	1	-1.721	4.5389	0.7046	OZP	1	-0.259	0.1836	0.1583

Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
	275	0.2957409	1	-7.003	8.0794	0.3861	1	-2.2313	6.5785	0.7345	OAE	1	0.0427	0.1218	0.7262
	275	0.2957409	1	18.8783	22.3309	0.3979	1	-2.2596	5.8098	0.6973	OCE	1	-0.2665	0.2597	0.3047
	275	0.2957409	1	46.6831	15.3051	0.0023	1	-2.8407	4.1026	0.4887	OZE	1	-0.5371	0.1629	0.001
	270	0.2627774	1	-10.1229	8.1772	0.2157	1	0.8231	9.7842	0.933	IAP	1	0.073	0.0992	0.4617
	281	0.2910125	1	-3.404	13.3892	0.7993	1	-2.1389	6.9881	0.7595	ICP	1	-0.0102	0.137	0.9409
	281	0.2910125	1	11.1195	12.6251	0.3785	1	-2.3333	3.9846	0.5581	IZP	1	-0.1508	0.125	0.2277
	276	0.2627087	1	-5.4472	6.3314	0.3896	1	-0.8677	8.4866	0.9186	IAE	1	0.0132	0.0914	0.8851
	287	0.2903561	1	-0.0804	9.1686	0.993	1	-2.2488	5.5021	0.6827	ICE	1	-0.0534	0.1135	0.6378
	287	0.2903561	1	1.3699	5.0169	0.7848	1	-1.6178	4.723	0.7319	IZE	1	-0.0657	0.0567	0.2471
0200 - 0400	404	0.2713178	1	-11.7281	3.2624	0.0003	1	4.9024	1.4671	0.0008	OAP	1	0.0767	0.0333	0.0212
	406	0.2708037	1	-39.5582	8.2705	<.0001	1	6.2189	1.497	<.0001	OCP	1	0.3179	0.0729	<.0001
	404	0.2713178	1	-54.1818	15.4815	0.0005	1	7.6073	2.1477	0.0004	OZP	1	0.4223	0.1294	0.0011
	404	0.2713178	1	-12.5955	3.5121	0.0003	1	4.7011	1.4173	0.0009	OAE	1	0.1151	0.0481	0.0168
	404	0.2713178	1	-53.4256	8.8314	<.0001	1	7.5742	1.3909	<.0001	OCE	1	0.5271	0.0927	<.0001
	404	0.2713178	1	-36.3099	13.0647	0.0054	1	4.987	1.7278	0.0039	OZE	1	0.3155	0.1276	0.0134
	405	0.262177	1	-14.6224	4.6639	0.0017	1	15.7989	4.5483	0.0005	IAP	1	0.0932	0.0522	0.0742
	409	0.2697488	1	-10.1304	5.5825	0.0696	1	4.478	1.7171	0.0091	ICP	1	0.0551	0.0549	0.3158
	409	0.2697488	1	-16.9238	7.3305	0.021	1	5.9313	2.1253	0.0053	IZP	1	0.1095	0.0639	0.0866
	407	0.2620037	1	-9.7815	3.5412	0.0057	1	13.0163	4.4099	0.0032	IAE	1	0.0402	0.0437	0.3575
	411	0.2695403	1	-9.437	5.0912	0.0638	1	4.3002	1.6147	0.0077	ICE	1	0.0563	0.0585	0.3363
	411	0.2695403	1	-17.7483	6.6785	0.0079	1	5.3795	1.7331	0.0019	IZE	1	0.1343	0.0669	0.0446

Time Period	N-Value	Awake Mean	DF	Intercept Estimate	Standard Error	p-value	DF	Covariate Effect Estimate	Standard Error	p-value	Predictor Variable	DF	Predictor Variable Estimate	Standard Error	p-value
KEY															
OAP = Outdoor A-Weighed Peak Level															
OCP = Outdoor C-Weighted Peak Level															
OZP = Outdoor Flat-Weighted Peak Level															
OAE = Outdoor A-Weighted Sound Exposure Level															
OCE = Outdoor C-Weighted Sound Exposure Level															
OZE = Outdoor Flat-Weighted Sound Exposure Level															
IAP = Indoor A-Weighted Peak Level															
ICP = Indoor C-Weighted Peak Level															
IZP = Indoor Flat-Weighted Peak Level															
IAE = Indoor A-Weighted Sound Exposure Level															
ICE = Indoor C-Weighted Sound Exposure Level															
IZE = Indoor Flat-Weighted Sound Exposure Level															

Appendix K: Complaint Risk Criteria

Risk of Noise Complaints	Large Caliber Weapons Noise (Unweighted Peak Level in dB)
Low	< 115
Medium	115 – 130
High	130 – 140
Risk of physiological damage to unprotected human ears and structural damage claims	> 140

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14. ABSTRACT

Training during the hours of darkness is a necessity for the Army and other branches of the Department of Defense (DoD). Nighttime training is needed to ensure military forces are ready for combat, but installations also endeavor to minimize community noise disturbance and resulting negative public reaction. As a result, most installations restrict nighttime training or enforce training curfews to reduce the negative impact of the nighttime training noise on local residents. There is, however, little research-based guidance on the types of restrictions and curfews needed to effectively reduce the negative impact. Consequently, current training restrictions may sacrifice more training capability than necessary.

During the fall of 2004 a field study was conducted adjacent to a military installation to determine if there are preferred times to conduct nighttime training. The results of this research project clearly and strongly indicate that community disturbance is more effectively reduced by conducting training between 0000 and 0200 hours, and avoiding noisy training during the evening hours before midnight. These findings suggest that night-time training should be postponed until after midnight in order to effectively reduce the negative impact of nighttime training on local residents and to preserve nighttime training capabilities throughout DoD.

15. SUBJECT TERMS
noise assessment, sound management, blast noise, training lands, USACHPPM

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